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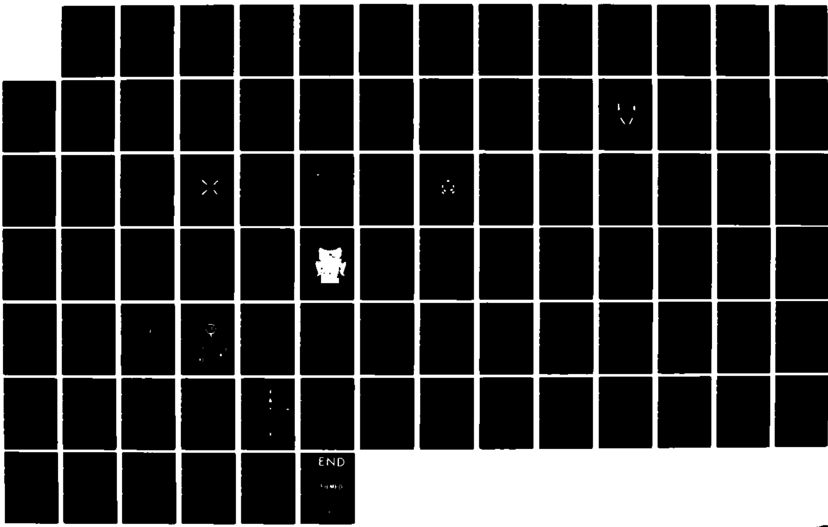

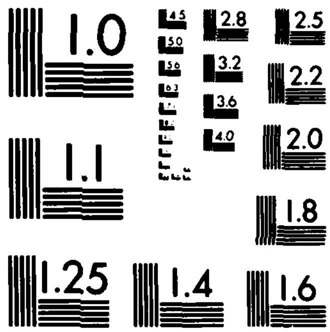

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AD-A148 984

" A Methodology for the Determination of Rotary Wing Aircraft Vulnerabilities in Air-to-Air Combat Simulation "

Major Kenneth L. Travis
HQDA, MILPERCEN (DAPC-OPA-E)
200 Stovall Street
Alexandria, VA 22332

Final report 23 November 1984

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A thesis submitted to the Georgia Institute of Technology, Atlanta, Georgia in partial fulfillment of the requirements for the degree of Master of Science (Systems Analysis).

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AIR-TO-AIR	ASPECT ANGLE
PROBABILITY OF DETECTION	MODEL RECALIBRATION
PROBABILITY OF MISSILE LAUNCH	TACTICAL TRAINING
PROBABILITY OF ACQUISITION	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This research effort proposes a methodology to calculate an aircraft's vulnerability in an air-to-air engagement. The primal processes of such an engagement-- detection, acquisition, missile launch, missile intercept and probability of kill-- are modeled using an electro-optical device as the source of target detection.

The resultant probability of kill is depicted as a function of range for a given aspect angle. This constitutes an enhancement over the tradi-

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tional kill/no kill representation in that the entire distribution may be obtained for the selected engagement angle.

Since little historical or actual test data is available for comparison, evaluation requirements for such a conceptual methodology is discussed. A recalibration process is recommended which will allow the refinement of the model as tests are conducted and observed data becomes available.

Applications of the methodology results are recommended for the areas of research and development and pilot tactical training. A pilot decision logic based upon the results of executing the metodology is proposed.

A METHODOLOGY FOR THE DETERMINATION OF ROTARY WING AIRCRAFT VULNERABILITIES IN AIR-TO-AIR COMBAT SIMULATION

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

by

Kenneth L. Travis

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial and Systems Engineering

Georgia Institute of Technology

December, 1984

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A METHODOLOGY FOR THE DETERMINATION OF ROTARY WING AIRCRAFT VULNERABILITIES IN AIR-TO-AIR COMBAT SIMULATION

Approved:

Leslie G. Callahan, Chairman

Jerry Banks

Daniel P. Schrage

Date approved by Chairman ________

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to those professionals who were instrumental in the successful completion of this research effort.

A very special thanks is due Dr. Leslie G. Callahan, chairman of my thesis committee, whose encouragement and direction were invaluable in the accomplishment of this task. His insights and knowledge of military modeling have provided me an education which far exceeds that which can be captured in the classroom.

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Last, and most importantly, I want to thank my wife, Helena. For eighteen months she has abandoned her personal desires and wishes. In their place she has returned unfailing encouragement, constant support and timely advice so that my academic experience might become a reality. Because this thesis could not have been completed without her help, it is dedicated to her.

TABLE OF CONTENTS

TABLE OF CONTENTS Cont'd.

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

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CHAPTER I

INTRODUCTION

Background

> If theory investigates the subjects which constitute War; if it separates more distinctly that which at first sight seems almagamated; if it explains fully the properties of the means; if it shows their probable effects; if it makes evident the nature of objects; if it brings to bear all over the field of War the light of essentially critical investigation -- then it has fulfilled the chief duties of it's province.
>
> -- Clausewitz[17]

The complexity and magnitude of modern day military systems have resulted in a proliferation of system modeling and analysis. This modeling and analysis represents a concerted effort to expose the underlying theories and internal structure addressed by Clausewitz.

The last 30 years have brought tremendous technical advances to the battlefield. The potential lethality of today's armed conflict is as never before experienced in the history of mankind. Paralleling this enhanced sophistication in weapons development and employment doctrine are comparable advances within the analytical community to model and simulate these systems. Pivotal to this advancement has been the development of the computer. This computational capacity has permitted the analysis of systems previously exempt from critical investigation due to their inherent complexities. Consequently the military, utilizing models and simulation primarily for training, education and design[6], has acquired a multitude of models covering a broad spectrum of functional applications. Figure 1, developed by James G. Taylor[35], offers a visual representation of various types of models and simulations and how each varies with

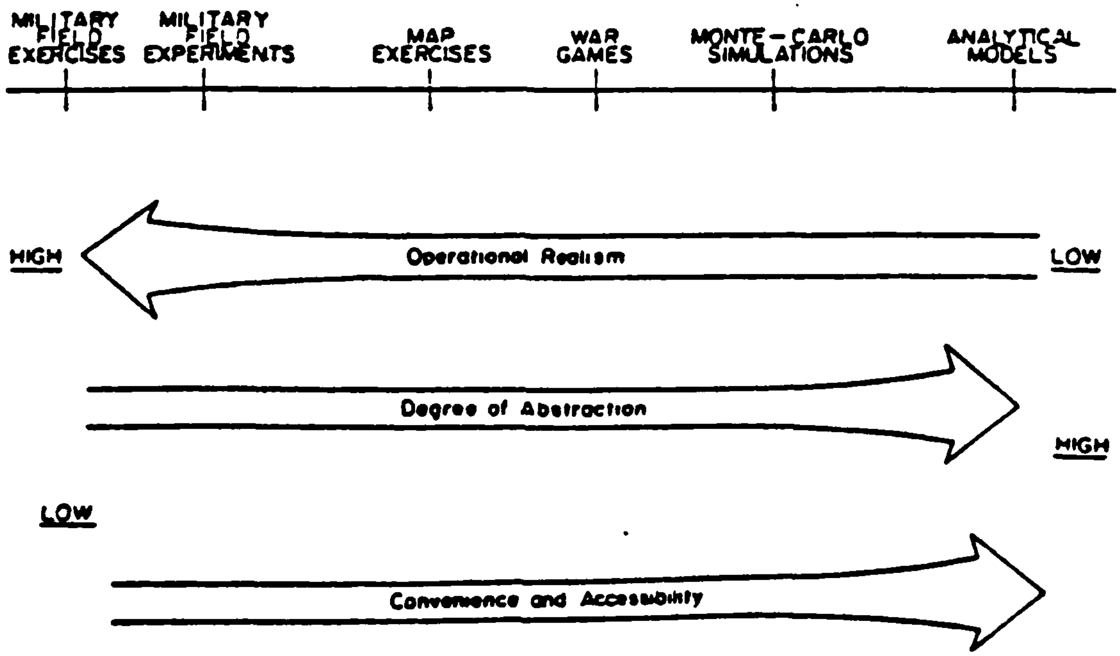

Figure 1. The Spectrum of Types of Combat Models

respect to realism, abstraction, convenience and accessibility. The breadth and scope of current analytical efforts are illustrated further by Lawrence J. Low's[22] matrix depiction of wargaming activities in Figure 2.

In many instances military models and simulations have been developed without any analytical community effort to direct and coordinate their advancements. This has resulted in the lack of a common methodological basis for development and classification for the application and use of the developed models. Table 1 depicts many of the military model taxonomies that exist today[17].

In order to provide structure and a common basis of understanding for this research effort, Dr. Leslie G. Callahan's[6] definition of modeling and simulation will be adopted:

Modeling - A specific way of expressing a theory which reveals the internal structure

Simulation - Experimentation with models - - use of computers as tools for modeling

The last decade has produced substantial technical advancements in U.S. Army Aviation. Aircraft, weapon, and pilot support systems have progressed to the degree that new tactical employment doctrine is under development to insure these system capabilities are fully exploited on tomorrow's battlefield. The U.S. Army analytical community is actively engaged in an effort to establish accurate, representative models and simulations of these critical systems.

One tactical employment consideration of increased potential for occurrence is that of the air-to-air (ATA) engagement. Previously a concern for primarily the U.S. Air Force, advancements in aircraft, munitions and doctrine

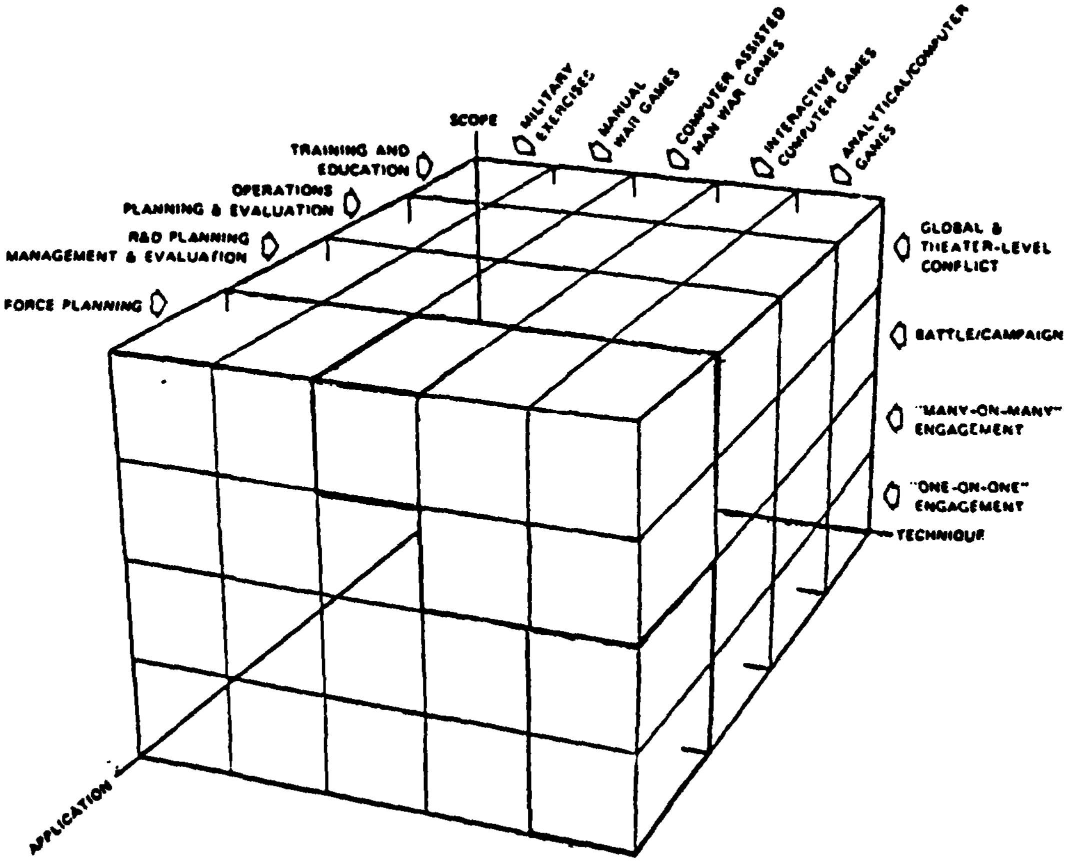

Figure 2. Gaming Classification Matrix

Table 1. Military Model Taxonomies

1. Models by Technique or Level of Abstraction
   * Analytical
   * Computer Simulation
   * Wargaming
   * Field Experiment

2. Models by Application or Purpose
   * Battle Planning
   * Wartime Operations
   * Weapon Procurement
   * Force Sizing
   * Human Resource Planning
   * Logistic Planning

3. Models by Scope or Scale
   * Micro - -Single Unit Engagements
   * Medial - -Multiple-Unit Engagements
   * Macro - -Theater Level Engagements

4. Ad Hoc and Standing Models
   * Ad Hoc - -Models built for specific decision making
   * Standing - -Maintained, operated and improved on a continuing basis

5. Models to Describe, Prescribe, Predict
   * Descriptive - -Reproduce essential processes of phenomenon modeled
   * Prescriptive - -Specifies a course of action
   * Predictive - -Analysis of other than initial conditions and situations

6. By Properties: Transparency, Reproducibility, etc.
   * Consistency
   * Enrichment Potential
   * Experimental Validity
   * Military Realism
   * Credibility
   * Flexibility
   * Physical Reasonableness
   * Responsiveness
   * Interface Potential
   * Sensitivity of the Model
   * Resources Required
   * Visibility to the Analyst
   * Visibility to the User
   * Technical User Capability

have made a helicopter ATA engagement a probable event as well.

The general purpose of this research is to investigate the primary processes essential to an ATA engagement involving U.S. and Threat helicopters. An analytical model will be developed detailing the fundamental functions which ultimately result in establishing an aircraft's vulnerability (probability of kill). The methodology will then be extended to allow the determination of a probability of kill threshold for a given range and engagement aspect angle.

Problem

> Just as tanks have always been the most effective weapon against tanks, helicopters are the most effective means of fighting helicopters. Use of helicopters by both warring sides will inevitably lead to clashes between them. Like tank battles of past wars, a future war between well equipped armies is bound to involve helicopters.
>
> -- Major General Belov,
> Noted Soviet military author[8]

The potential for ATA engagements involving U.S. Army helicopter aircrews results from three primary considerations: (1) development and adoption of ARMY 21 (formerly the Airland Battle Doctrine, with particular emphasis on the Deep Battle), (2) technical advances in aircraft and munition design such as the AH-64 Apache aircraft, Hellfire and Stinger missiles, and (3) the priority given to anti-tank defense under current Soviet armed forces employment doctrine.

However the military analysis community has experienced difficulty in maintaining step with the developments in hardware and doctrine essential to the ATA engagement. To date, there have been no military-generated models or simulations which adequately represent a helicopter ATA engagement in a tactical scenario. The major analysis efforts have been performed by leaders in the rotary wing aircraft industry and private contractors.

In light of these assertions, the central problem addressed by this research is how to model the fundamental processes of an ATA engagement so that the internal structure may be accurately exposed and represented. The benefits of a detailed, representative analytical model as the basis for incremental model building and simulation-aided analysis will be explored.

Research Objective

The primary objective of this research is to develop a methodology to determine an aircraft's vulnerabilty in an air-to-air combat scenario. This investigative effort will incorporate four intermediate objectives to assist in accomplishing this goal.

1. Identify, analyze and accurately model those processes essential to an air-to-air engagement.
2. Extend the model to allow for the determination of a vulnerability (probability of kill) based upon a given range and engagement aspect angle.
3. Identify additional areas of analysis such as tactical doctrine and aircraft design which might be enhanced through incorporation of such a model.
4. Analyze and discuss the validation and recalibration requirements of such an air-to-air engagement model.

CHAPTER II

RESEARCH APPROACH

General Observations

A review of the current military modeling effort indicates a multitude of models, simulations and wargames depicting land combat. The "Catalogue of War Gaming and Military Simulations Models", published by the Joint Chiefs of Staff[29], provides details on 363 military simulations and wargames in use throughout the worldwide defense community. The "Catalogue of War Games and Combat Simulations," prepared by the Office of the Deputy Under Secretary of the Army (Operations Research)[9] describes 107 war games and simulations by functional level (primarily one-sided) and force level(two-sided). These simulations and wargames are presently being utilized by United States, British, Canadian and Australian defense forces.

The most significant observation resulting from this literature review is the lack of a single military-generated model or simulation which addresses a rotary wing air-to-air engagement. This void of modeling application supports the findings of a 1980 Government Accounting Office (GAO) report which concluded that

> From a scientific point of view, the present 'Understanding of War' — insofar as the effectiveness of conventional ground and tactical air forces are concerned - - is in a relatively primitive state. Basic research aimed at understanding the fundamentals of combat is needed, but quantitative or numerical techniques have not been systematically applied to achieve these discoveries[34].

The lack of expertise and advancement in the subject area of air-to-air combat modeling can be attributed to two primary factors: (1) the rapidity with which the technologically sophisticated hardware required to stage an engagement has been developed, and (2) the inability to adequately represent the inherent

complexity of the engagement.

The modeling of an ATA engagement is inherently complex because it consists of two man-machine systems simultaneously attempting to achieve the same goal -- win the air battle. Modeling a purely mechanical system is straightforward. Once the primary functions have been defined and represented, the model (or simulation) can be expected to provide consistent results over time due to its mechanical nature. However, the introduction of a human controller into the model to form a man-machine system makes the modeling effort considerably more complex. It is most difficult, if not impossible to adequately model the unbounded human decision making process. Our case here is confounded by different aircraft with different capabilities, flown by pilots with different training philosophies and tactics, but each attempting to achieve the same objective. Figure 3 highlights many of the system components which require modeling to adequately represent the actual encounter.

Two approaches to modeling this system may be considered. First, an attempt could be made to represent all the component parts in the same model. This approach traditionally requires a lengthy development period and may ultimately contain numerous effectiveness-questioning assumptions and limitations. A second approach would allow related components to be modeled as separate simulations. The results of one component simulation could be used to provide input to the next. This is similar to the procedure used by the Directorate of Combat Developments (DCD), U.S. Army Aviation Center, Fort Rucker, Alabama[16] to conduct trade off analysis (TOA) for the Light Helicopter, Experimental (LHX) studies. Although the models utilized by DCD to conduct the TOA were not specifically designed to model air-to-air engagements, many of the primal

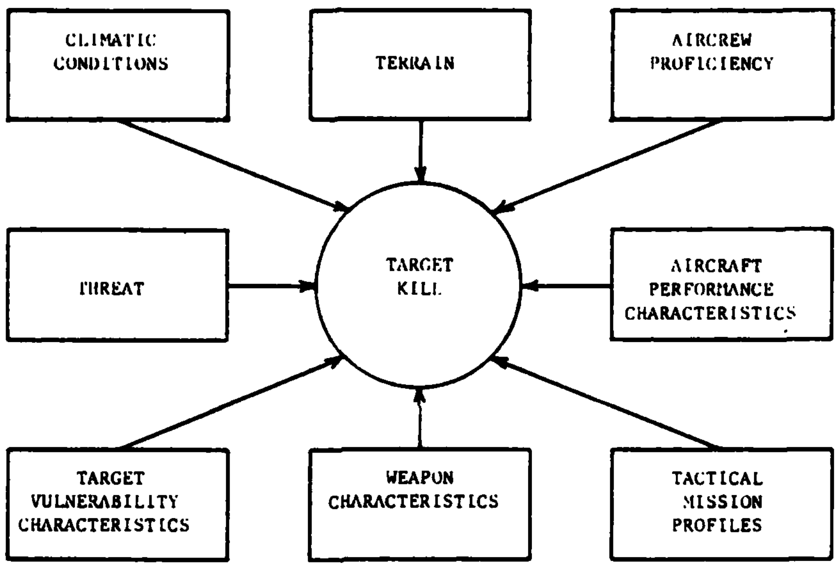

Figure 3. Air-to-Air Engagement System

processes required in an ATA engagement sequence are modeled in these separate simulations. These models, as well as a model developed by the Georgia Tech Research Institute, will be summarized in the following sections.

Helicopter Mission Survivability Model (HELMS)

HELMS is a computer simulation model designed to provide a highly defined aircraft flight path history for a given mission profile. The model was developed by the U.S. Army Engineer Waterways Experimental Station (WES), Vicksburg, Mississippi[36]. Additionally, the model will provide data on the physical details encountered on a given flight as well as speed, maneuverabilty, agility and crew workload requirements for a selected airframe designation. Intervisibility segments, defined as periods in which RED defenses establish line of sight and possess the capability to engage BLUE forces, are also computed.

Input

The input to HELMS, depicted in Figure 4, is primarily of two categories: terrain and selected scenario.

The terrain input allows the user to specify both the contours of the land and the impact of its vegetation. In light of the low altitude and nap-of-the-earth (NOE) flight techniques espoused by Army aviation, this latter capability is highly desirable and contributes significantly to the resolution of the model.

The scenario input allows the user to define the location, capabilities and performance characteristics of Threat air defense and surface-to-air missile (SAM) systems. The selected flight path is encoded from point to point, with user selected altitude and airspeed restrictions. Aircraft performance characteristics may also be defined.

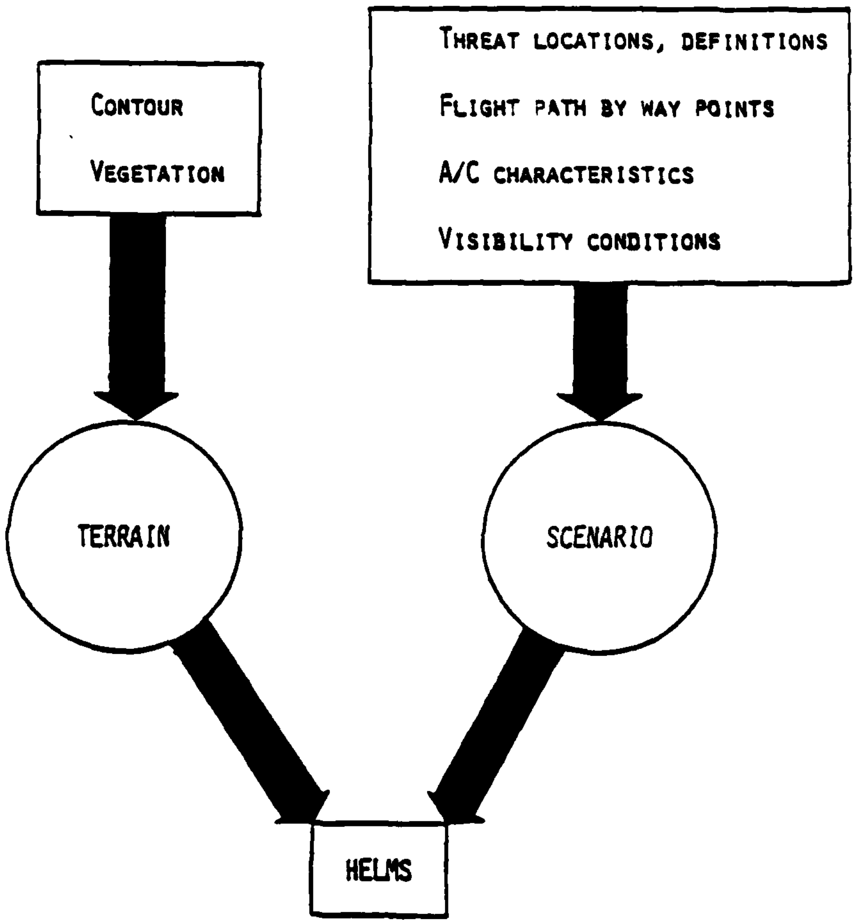

Figure 4. HELMS Input

Additional Features

Table 2 highlights numerous additional features which HELMS employs to generate a realistic flight path history.

Height data of such flight obstructions as urban areas, buildings, water towers, etc. are superimposed on the contour grid by grid. This allows the aircraft to encounter and negotiate representative flight hazards along the designated flight path.

The battlefield area modeled, particularly the Mideast region, is one of the largest (in terms of square kilometers) of any combat simulation model.

The flight path generation function computes an optimum flight path between the designated points, consistent with the plotted terrain features and aircraft performance limitations. This allows the aircraft to traverse the course in a terrain conforming manner much like an actual pilot would when conducting NOE operations.

Output

The ouptut generated by HELMS, summarized in Figure 5, is classified as flight path data and specific reports.

The flight path data describes the movement of the aircraft through a time history with respect to altitude and heading. The time period of intervisibility in which a BLUE helicopter could be engaged by a RED weapon system are also calculated and plotted.

The specific reports generated are time histories of aircraft performance characteristics, Threat weapon engagements and needs (tactics and mission productivity) analysis and ultimately, the survivabilty report.

The output of this simulation model will be used as input to the Helicopter Survivability Assessment Model (HSAM), described in the next section.

Table 2. HELMS Features

- DIGITIZED DATA BASE
  - *PROVIDED BY THE DEFENSE MAPPING AGENCY
  - *REAL WORLD MAPPING
  - *COMMON TO MOST OTHER COMPUTER SIMULATIONS
- VEGETATION
  - *HEIGHT DATA SUPERIMPOSED ON CONTOUR
- UNLIMITED BATTLEFIELD
  - *35 X 94 KM EUROPE
  - *16 MAP SHEETS EACH 24 X 27 KM MID-EAST
- TERRAIN SHIELDING
  - *INTERVISIBILITY
  - *A/C SURVIVABILITY
- FLIGHT PATH GENERATION
  - *HELICOPTER DYNAMICS
  - *TERRAIN FEATURES
  - *OPERATOR INPUT VIA FLIGHT POLICIES

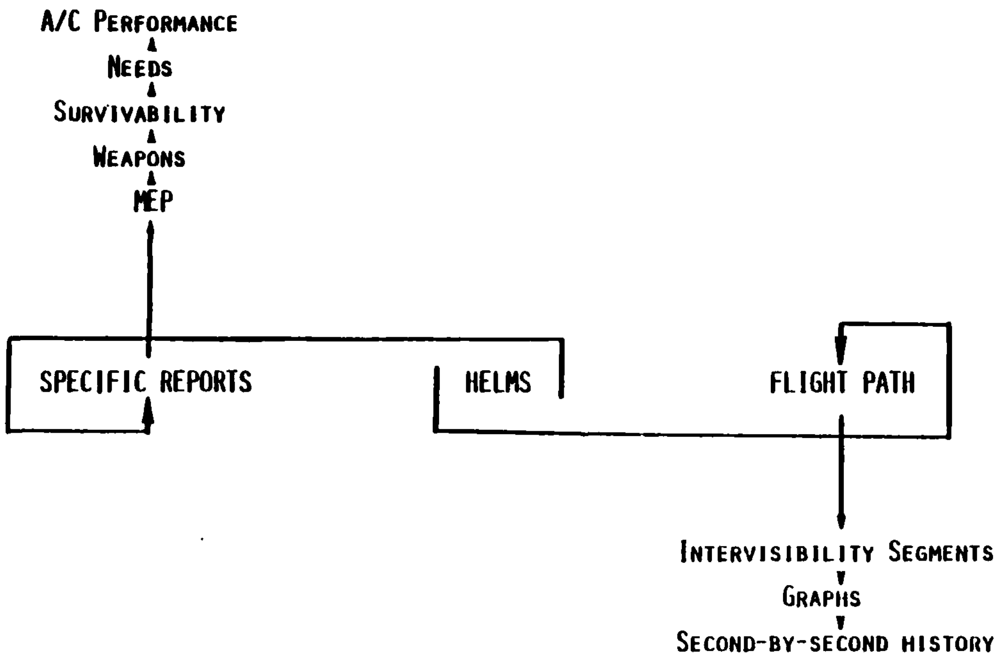

Figure 5. HELMS Output

Limitations

The limitations of HELMS, illustrated in Table 3, are severe if the user desired to simulate a rotary wing ATA engagement. The fact that no air-to-air is played and the BLUE forces do not have the capability to fire would cause the model to be declared unacceptable. However, if the user's objective is to generate accurate flight path data, then this model is most satisfactory. This is the primary function the model performs for DCD's analysis. The model's worth is further demonstrated by the fact that it allows modeling and analysis for four of the eight system processes highlighted in Figure 3.

Table 3. Major HELMS Limitations

NOT A TRUE FORCE ON FORCE MODEL
- BLUE does not fire
- BLUE receives no warnings
- BLUE does not react to RED
- No air-to-air played

Helicopter Survivability Assessment Model (HSAM)

HSAM is a combat simulation model designed to assess the value of alternative aircraft survivability measures. Primarily a research and development tool, the model was developed by Scientific Applications Incorporated for the Applied Technology Laboratory, Fort Eustis, Virginia[6]. HSAM utilizes flight path data generated by HELMS to compute a deterministic survivability quotient for a single helicopter against a single RED ground-to-air defense system. The

engagements are one-on-one and incorporate RED's ability to detect, track and achieve lock-on. Figure 6 depicts the primary functions performed in HSAM.

Input

Input to HSAM, summarized in Figure 7, includes Threat, target and environmental data and operational conditions.

Data input on Threat defense systems include the ability to detect, track, lock-on and hit or kill the target. Data on 11 different weapon systems are available for selective inclusion in the model.

Target data includes definition and descriptions of the aircraft which allow its respective mobility, detectability and vulnerability to be assessed. This model allows the target aircraft to vary its flight path, make 360° turns and take evasive maneuvers to avoid incoming projectiles. This is a significant improvement over HELMS and considerably more representative of the action taken by a pilot in an actual combat scenario.

The environmental input is dependent upon the type of sensor being used. HSAM has the capability of modeling aural, visual, radar and infrared (IR) sensors. Each sensor allows defining input characteristics of the selected capability.

Operational conditions are defined by output from the HELMS model and include intervisibility segments, aircraft altitude, speed and maneuvers performed.

Additional Features

Table 4 delineates options available to assist the user in his analysis. These factors are necessary inclusions to any model which might be developed to simulate a rotary wing air-to-air engagement.

Output

The output generated by HSAM consists of a deterministically computed

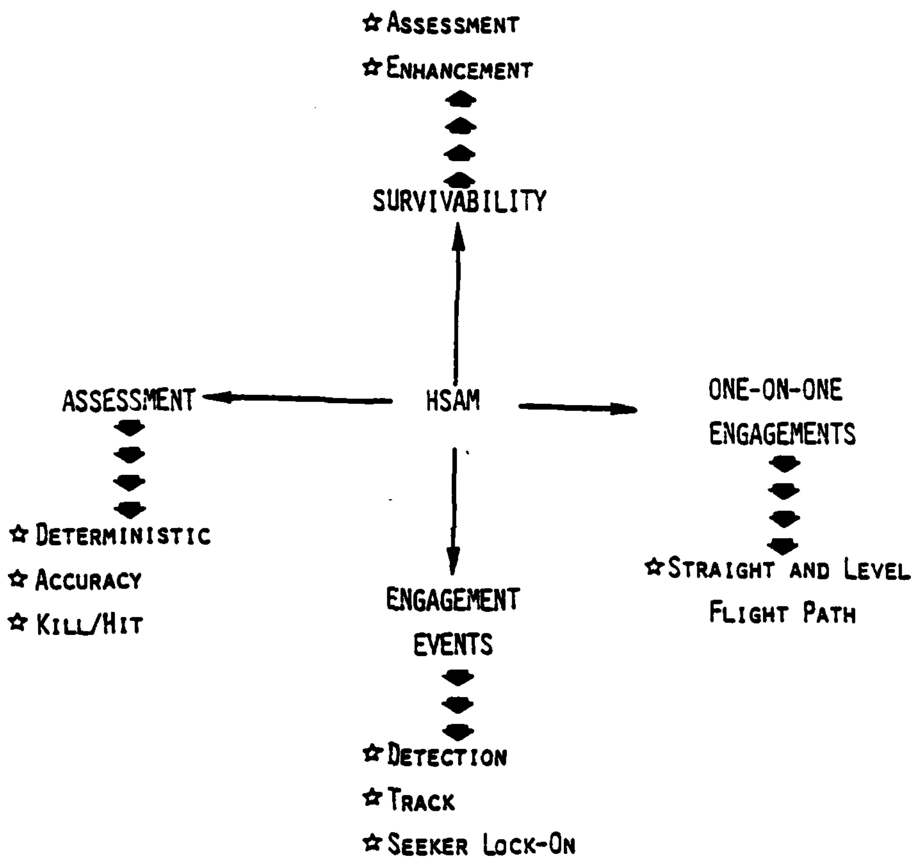

Figure 6. HSAM Primary Functions

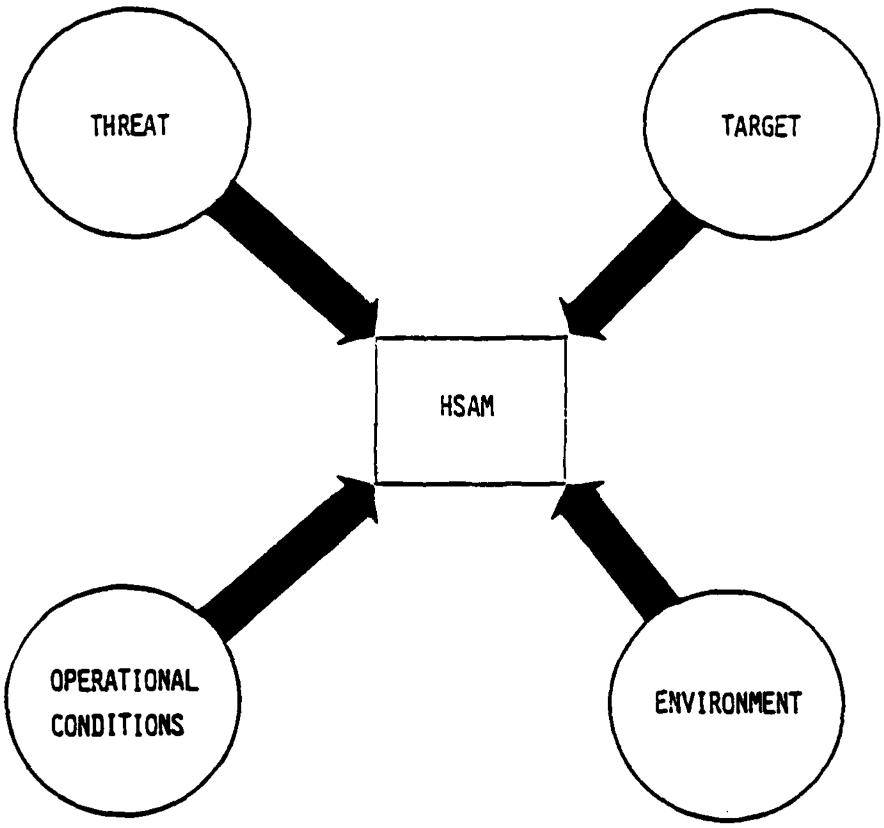

Figure 7. HSAM Input

probability of kill versus a selected sensitivity variable. Any single or combination of 21 sensitivity variables may be selected by the analyst. Sensitivity variables are primarily variations of the options listed in Table 4.

Limitations

Although the HSAM offers numerous capabilities not obtainable through HELMS, this model does not incorporate air-to-air engagements. This model does provide a dimension of aircraft maneuverability not evident in HELMS. However, the basic engagement is a ground based air defense or small arm Threat weapon system against an airborne target.

Helicopter Air Combat Effectiveness Simulation (HACES)

HACES is a force-on-force simulation developed at the unit action level. It was created by *Flight Systems Incorporated* of Newport Beach, California[37]. The simulation was developed to assist in the analysis of helicopter weapon and aircraft effects, design trade-offs and tactics development. The model allows for the selection of either stochastic or deterministic parameter values. HACES primary functions are highlighted in Table 5.

Input

Input to HACES, summarized in Figure 8, is similar to that of HSAM with a couple of noteworthy exceptions. Being a force-on-force model, the data base is more extensive (see Appendix C). In addition, the ability to simulate helicopter air-to-air engagements requires a greater degree of detail with respect to aircraft perf. mance capabilities. For instance, this model allows for user specification of low level, contour or NOE flight modes.

Additional Features

HACES incorporates a well defined Threat force for use in the simulation.

Table 4. HSAM Options

■ ASSESS THE SENSITIVITY OF HELICOPTER SURVIVABILITY TO PASSIVE SURVIVABILITY ENHANCEMENT MEASURES

- SIGNATURE REDUCTION
- PRESENTED AREA
- VULNERABILITY REDUCTION
- TACTICS
- MANEUVERS
- FLIGHT CONDITIONS

Table 5. HACES Primary Functions

UNIT ACTION - MONTE CARLO SIMULATION

ENGAGEMENTS

-- Air-to-Air

-- Surface-to-Air

-- Air-to-Surface

MODELS

-- Helicopter Performance Capability

-- Air Defense Units

-- Weapons Employment

-- Tactics

TERRAIN

-- Macro

-- Micro

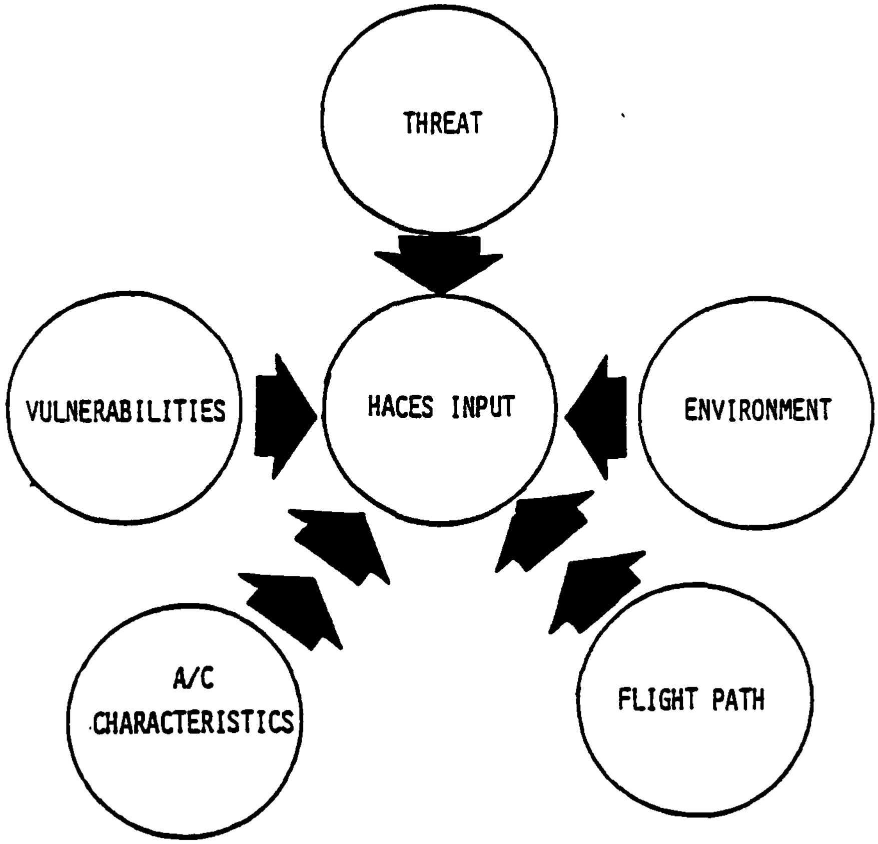

Figure 8. HACES Input

This capability includes the determination of force mixes, mission profiles and tactics employed. Similar capabilities exist for BLUE forces.

The terrain depiction in this model is classified as macro or micro. The macro category incorporates those terrain characteristics defined by large contour intervals. The micro terrain modeling comprises features such as trees, gulleys, small hills and buildings which might not be evidenced on a topographic map. These combined modeling concepts provide accurate, realistic analysis of NOE flight, detection and survivability.

Output

The output provided by HACES consists of killer/victim scorecards and tabulated or graphical time histories of the simulation run. This format is typical of force-on-force models and provides no significant enhancements.

Limitations

Although the HACES model provides a greater total battlefield modeling capability than HELMS or HSAM, the latter provide a greater resolution in their respective functions. Consequently, the Directorate of Combat Developments (DCD), U.S. Army Aviation Center utilizes HELMS to generate detailed flight path data, which they then use as input to HSAM. HSAM uses the flight path data to calculate aircraft survivability against air defense systems. Finally, both model's output is used as input to HACES, in which the dimension of air-to-air is incorporated.

General Effectiveness Model (GEM)

The GEM is a time-stepped probabilistic expected value model designed to analyze and evaluate the effectiveness of electronic warfare measures with respect to combat survivability. The model was developed by the Georgia Tech Research

Institute (GTRI), Atlanta, Georgia[25]. The model allows the analysis of complex scenarios involving offensive and defensive forces in an integrated air defense system. Utilizing an expected value methodology, the GEM has been used to evaluate equipment design, assess performance profiles and conduct trade-off analyses.

The scope of a given simulation can be highly defined through the selective inclusion of the desired sensitivity variables. The capability of the GEM allows for a scenario to be constructed which may incorporate a maximum of 80 radar positions, 20 penetrators and flight profiles with 320 breakpoints. The model also employs a terrain masking capability. Electronic countermeasures which may be included are active, passive or a combination of both.

Input

Input to GEM includes defining parameters for aircraft, radars, weapon and electronic counter measure systems. The scenario, including Threat location, terrain data and flight profiles must also be input.

A distinct advantage to the input process of GEM is the manner in which the database is structured and maintained. The database is developed generically, making extensive use of measured data from tests and experiments. These tests have been replicated and provide the basis for expected values used in the model. Deterministic simulation models are used to define parameters for hardware for which no test or experimental data is available.

This method of database management offers a degree of flexibility for refinement of the model. First, as additional tests and experiments are performed, the generic structure allows expeditious updating of hardware system parameters. Second, the generic modular structure allows the user to define his own hardware

system through the parameterization of selected sensitivity variables. This capability is particularly useful when analyzing system requirements.

Output

The primary output provided by GEM is mission survivability as measured by aircraft attrition. This output provides the nucleus for mission and survivability analysis, electronic countermeasures effectiveness evaluations, operational test and evaluation and tactics optimization. Specific output data includes the number of aircraft hits and kills for a given scenario.

Due to the modular development and expected value methodology, GEM runs faster than real time. This allows a greater number of parametric and sensitivity analyses to be conducted within the same time/cost constraints.

Additional Features

The modular structure of GEM provides a framework by which the simulation can be performed with the given basic submodels inherent in the model, or auxiliary computer models with a higher resolution for specific functions may be substituted. This allows a tremendous degree of flexiblity in designing a model with the highest degree of resolution for a given analysis.

Consequently, the GTRI has developed eight separate computer models which may be input into the GEM structure to perform a specific function. The functional areas are represented by radar cross section, Threat vulnerability, missile fly out, weapon effectiveness, mission analysis, command, control and communication, special purpose equipment and campaign models.

Two of the larger models developed which can be utilized in conjunction with GEM are the Automated Encounter Model (AEM) and Self-Protection Analysis Model (SPAM).

The AEM is used to simulate an integrated air defense system against a penetrating aircraft. The model may also be used to evaluate multiple systems simultaneously. Air defense weapon assignments are made on established rules of engagement. The model maintains a time history of all engagements as well as weapons expended and the probability of aircraft attrition. With an execution time faster than real time, the model runs until all aircraft are attrited or the scenario is completed.

The SPAM is a tracking radar model which deterministically evaluates chaff, infrared flares, active electronic countermeasure and aircraft maneuvers. Input to the model includes aircraft performance characteristics, radar/infrared tracking system surface-to-air and air-to-air missiles and anti-aircraft artillery. Model output specifies time histories of jamming-to-signal ratio, missile tracking error and break-lock that occurs when chaff or flares are dispensed. The combined use of GEM and SPAM allows an analyst to evaluate the effects of tactics, command and control and electronic countermeasures in air-to-air engagements.

<u>Limitations</u>

Although GEM provides a high degree of resolution for the modeled functions, it is limited by its inability to represent a rotary wing air-to-air engagement. The primary focus of the model is directed toward the surface-to-air scenario. However, many of the primary processes required in an air-to-air engagement are well defined and employed in the execution of the model.

CHAPTER III

AIR-TO-AIR ENGAGEMENT METHODOLOGY

Overview

An air-to-air engagement, as described in Chapter II, is a highly complex assemblage of men and machines, each striving to achieve the same goal. The determination of an aircraft's vulnerability, defined herein as an aircraft's susceptability to damage or destruction when impacted by an explosive projectile, can be established through the modeling and analysis of such a system.

A helicopter's vulnerability is affected by many factors and considerations. Among these are detectability, flight dynamics, crashworthiness, vulnerability of the crew, vulnerability of the airframe to ballistic penetration, aircraft systems redundancy, countermeasures employed and the offensive weapon employment capability.

Although the methodology presented here determines an aircraft's vulnerability, in many studies and analyses the variable of concern is the resultant aircraft survivability. The probability of an aircraft surviving an air-to-air engagement, P_S, may be determined by the equation:

$$P_S = 1 - P_K \tag{1}$$

where

$$P_K = \text{probability of kill}$$

and may be determined by execution of the proposed methodology.

Essentially, the determination of a vulnerability coefficient is dependent upon the aircraft type, weapons systems, tactical doctrine and aircrew proficiency employed for a particular engagement scenario. The large number of variations for each of the above variables contributes to an enormous number of combinations if one should attempt to model all possible engagements. Obviously, such an attempt here would be over-zealous and beyond the scope of this investigation.

The analyst is continuously faced with the judgemental decision of exactly how much of the total system must be modeled to adequately and accurately represent its function. In order to limit the scope while maintaining the applicability of this methodology, only the primal processes of the engagement sequence will be modeled. These processes, illustrated in Figure 9, include the probabilities of detection, acquisition, missile launch, intercept and kill. In all cases, the characteristics of the essential elements of the engagement have been described as generically as possible. This approach was selected in order to enhance the applicability of the model while precluding the requirement to incorporate classified aircraft system and ballistic munition data.

The detection function in the methodology is performed through the use of an electro-optical device similar to that found on the Army's new AH-64 Apache attack aircraft. The Apache utilizes the Target Acquisition and Designation Sight (TADS) to provide target detection through the use of direct view optics, (DVO), forward-looking infrared (FLIR), television (TV), laser target designation and tracking. This system allows the Apache crew to detect, recognize and engage targets at extended standoff ranges during various climatic conditions.

The ballistic munition input requirements are modeled after the air-to-air Stinger (ATAS) currently under development. This missile will provide the U.S.

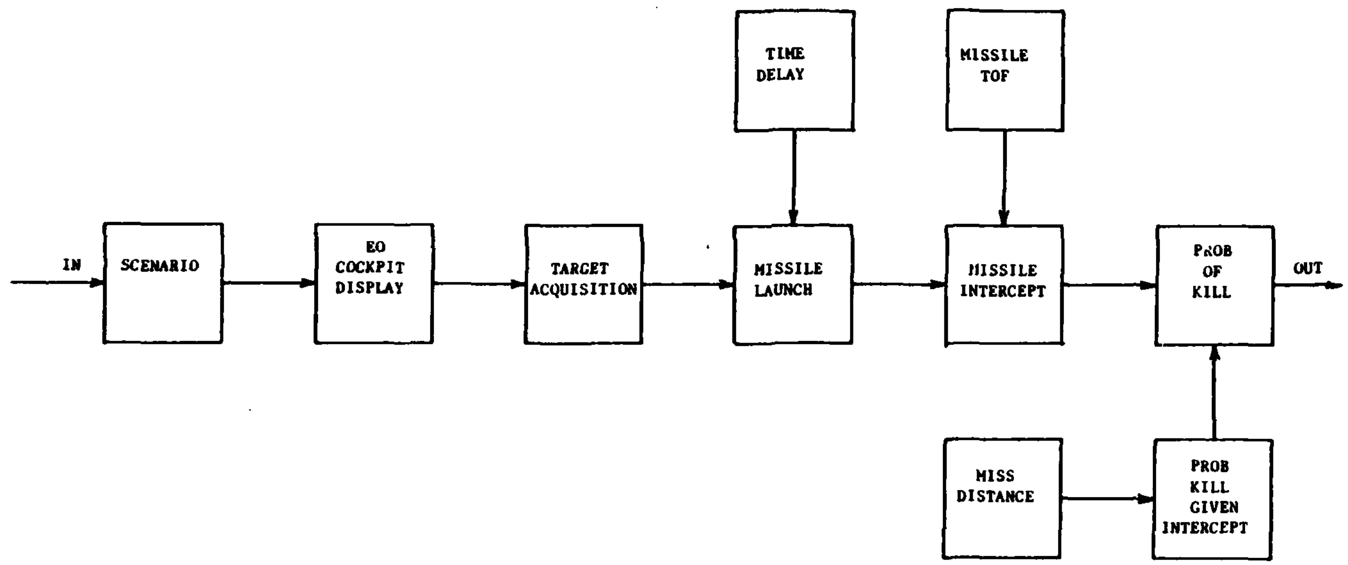

Figure 9. Primal Process Methodology

Army with a self-protection capability against both airborne threats and ground based air defense systems. With a range greater than 4,000 meters, the weapon will be a high velocity, fire-and-forget missile.

General Assumptions

Listed below are general assumptions which apply to the methdology which follows. These assumptions are employed to limit the scope and define the applicability of the model.

1. The model has been developed as generically as possible so that either a friendly or enemy helicopter may assume the role of the aggressor. Incorporation of appropriate airframe and weapon system data will allow vulnerabilities to be calculated for either force.
2. An electro-optical (EO) target detection capability has been selected to evaluate the detection function. Unaided visual, forward-looking infrared (FLIR) or aural detection capabilities can be substituted in lieu of EO without necessitating changes in the remainder of the methodology.
3. Target cueing is not modeled. The pilot is not alerted to a target's location by enemy fire, radar or another helicopter. The model requires the pilot to search the entire field of view to locate a target.
4. The pilots' glimpse rate equals 1/2 second. The sample time increment, Δt, is equal to 5 seconds.
5. The aggressor aircraft fires a single shot at the target. The aspect angle, defined as the angle of incidence between the missile and the target, does not vary within a single engagement.

6. No electronic countermeasures (ECM) are employed by the target aircraft in defense of the attack.
7. A sixth degree of freedom missile flyout model, characteristic of the specific missile chosen for study, is available to calculate the missile missed distance.
8. The target aircraft is coded to assess the resultant vulnerabilty when impacted by ballistic munitions. Detailed procedures for representation of the target are provided by Ball[4] and Scholz[32].

Single Glimpse Probability of Detection

Current technological developments in the rotary wing industry allow for the detection of targets by unaided visual, electro-optical (EO), forward-looking infrared (FLIR) and aural means.

The detection functions described in this methodology will be based upon electro-optical systems. EO detection was chosen for demonstration purposes and it should be noted that any or all of the remaining detection means could be included in an attempt to model the entire air-to-air engagement system.

A simplistic, straight forward approach to defining a generalized probability of detection function presented by Ross[30]. The model is:

$$P(x \in (t, t + dt)/x > t) \approx \frac{f(t)dt}{1 - F(t)} \tag{2}$$

$$= r(t)dt$$

where

x	=	random variable
f(t)	=	probability density function
F(t)	=	cumulative distribution function

and r(t) is the failure (or hazard) rate function and defined as

$$r(t) = \frac{f(t)}{1 - F(t)} \tag{3}$$

If one assumes the length of time to detect a target is exponentially distributed with a known rate λ, then $P(x \in (t, t + dt)/x > t)$ may be defined as $\lambda\, dt$. Then the probability of detection is dependent upon dt, the length of time the operator expends in search of a target.

Because the model by Ross is so generalized, it fails to adequately represent many of the technical aspects associated with an EO detection system. All of the required parameters are aggregated into the single rate λ. Although it allows for expeditious computations, the model fails to expose the internal structure of the process.

The probability of detection function described in this methodology is adopted from the Optical Zinger (OZ) model[27]. This model was selected as a basis because, unlike Ross[30], it adequately represents the internal structure of the EO system, is of moderate complexity and has been used in the past as a comparison standard in the development of alternative models.

The EO detection function is essentially a man-machine system requiring definition of both the physical and human operator subsystems for an adequate representation. The general equation

$$P_d = f(\text{human operator}) * f(\text{physical EO system})\ \Delta t \tag{4}$$

may be utilized to express the relationship between the probability of detection, P_d and the related subsystems for any time interval Δt.

Human Operator Subsystem

The human operator model is based upon the premise that the pilot will

normally detect a target through a series of glimpses at the television (TV) monitor located inside the cockpit. The AH-64 cockpit display is illustrated in Figure 10. The pilot mentally updates the depicted information at each glimpse, resulting in a probability of detection for each. The time duration of each glimpse may vary, but in this methodlogy it will be assumed to equal 1/2 second. The use of a glimpse time (t) equal to 1/2 second allows the calculation of the probability of detection in any desired time interval T by multiplying t by the number of glimpses, n, in the T interval.

The pilot's scanning capability is restricted by the operating limitations of the optical device. The operator will only be able to scan that portion of the total search area within the field of view of the device. The instantaneous field of view (FOV) as presented on the display to the pilot will be smaller than the total search sector. Then P_A, the probability that the pilot has the EO device directed to include the target in the instantaneous FOV can be calculated from[27]:

$$P_A = \frac{\theta_I}{\theta_T} \tag{5}$$

where

θ_I = instantaneous angular FOV of optical aide

θ_T = total angular sky sector to be search with aide.

The value of P_A is always determined by Equation (4) when the pilot is attempting to acquire a target. Upon detection of the target, $P_A = 1$.

In addition to the glimpse rate and FOV, the pilots ability to detect a target will be affected by the degree of clutter or distractive objects within the sight picture. Any degree of clutter greater than that of a plain sky will tend to

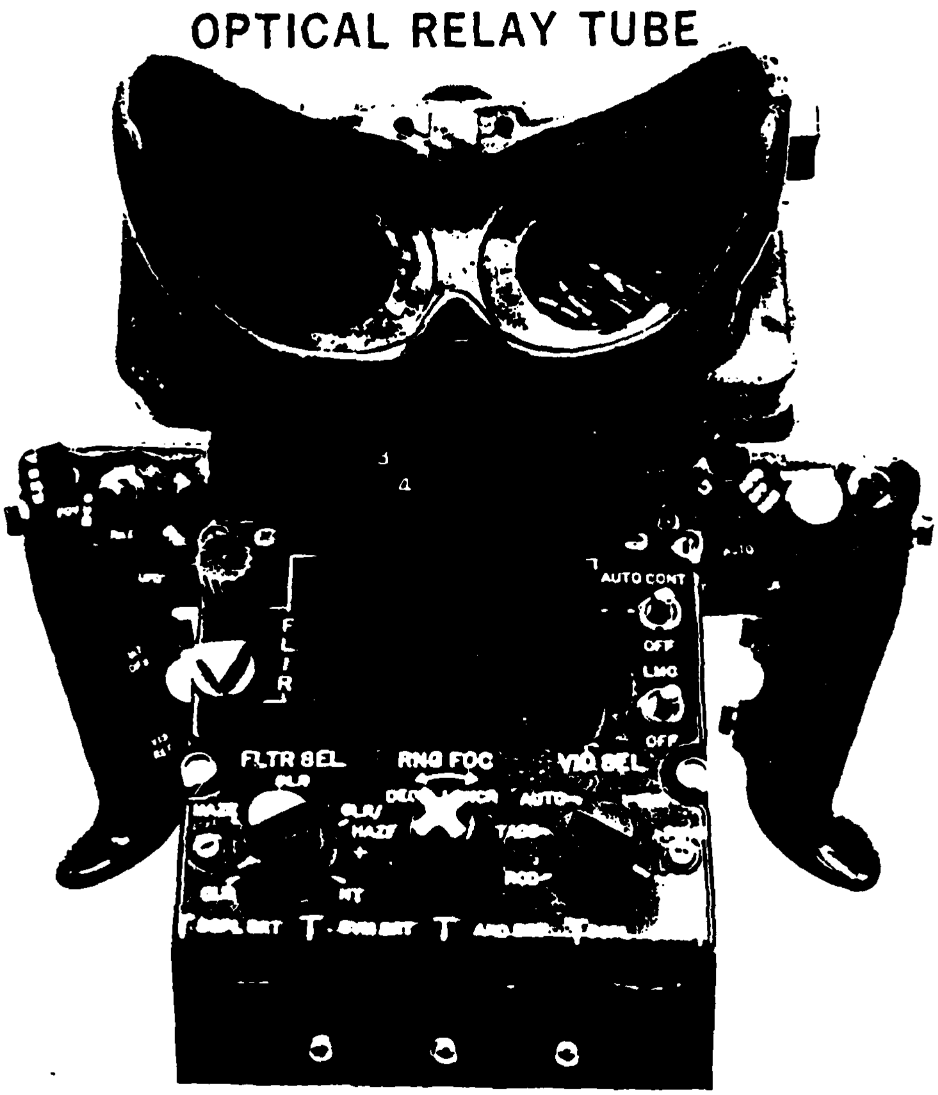

Figure 10. AH-64 EO Cockpit Display

degrade the probability of acquiring a target.

The degree of clutter which might be evidenced on the optical device is highly dependent upon the selected scenario. Such factors as geographical region (European vs. Mideast), specific engagement area (urban vs. open terrain) and seasonal characteristics (winter vs. summer) combine in varying degree to produce a specific amount of clutter on the display. This problem is compounded further in multiple shot engagements in which the degree of clutter will change as the relative position of the combatants change.

In order to account for the clutter which may be evidenced on the EO display, OZ establishes a scene complexity factor G, which is then used to reflect the degradation in target detection probability. The complexity factor is allowed to vary between 1 (plain sky) and 10 (highly cluttered). The greater the degree of clutter, the less likely a target will be observed, resulting in a smaller probability of detection for any glimpse. The factor $1/\sqrt{G}$ is multiplied by the other components of the single glimpse probability equation to incorporate the effects of clutter.

Additional research into clutter and resolution effects are detailed by Spratlin[33] and Schmieder et. al[31].

Physical EO Subsystem

The EO sensor and display incorportate the effects of image size, contrast, brightness and resolution in determining the probability of target detection. The contribution to the total probability of target detection provided by the physical EO subsystem is greater than that of the human operator.

The OZ model uses the variable P_{HS} to represent the probability that, given a target is displayed on the optical device, the clarity and contrast will be sufficient to allow the pilot to make a positive determination. To accomplish this,

the relationships between the target's size and background contrast, its position on the display with respect to the foveal axis and the degree of contrast required by the retina for absolute detection must be established. OZ uses the "Hammill-Sloan" probability functions to establish the relationships between these variables.

For a target to be detectable by the retina, the image contrast must exceed a specific threshold, C_T. This threshold is a function of the images' location with respect to the foveal axis and its angular size, and may be expressed as[27]:

$$C_T = .0334 + \frac{0.409}{\alpha^2} : \quad \theta \leq 0.8^\circ \tag{6}$$

or

$$C_T = .0352\,\theta^{0.24} + \frac{0.584}{\alpha^2}\,\theta^{1.6}; \quad \theta \geq 0.8^\circ \tag{7}$$

where

θ = angular location of the image with respect to the foveal axis in degrees

α = eye-apparent angular size of aircraft image in arc minutes

The value for α in Equations (6) and (7) is dependent upon the type of imaging system being used to perform the detection function. For the EO case, the value of α for air TV system may be determined by:

$$\alpha^2 = \left(\frac{L}{R_s D} \quad \frac{10800}{\pi}\right) \frac{HW}{\theta_V \theta_H} \tag{8}$$

where

L = representative aircraft dimension

R_s = aircraft-target slant range

D = distance from pilot's eye to display monitor screen

H, W = actual height and width of TV monitor screen

θ_v, θ_h = vertical and horizontal extent of TV system

$\frac{10800}{\pi}$ = conversion from radians to arc minutes

The values obtained from Equations (5) through (7) may be used to determine the value of P_{HS}, the probability that a target on the TV monitor will be observable by the pilot [27]:

$$P_{HS} = 0.5 + 0.5 \text{ erf } 2.946\left[\left(\frac{|C|}{C_T} - 1\right)\right] \tag{9}$$

where

$|C|$ = net resultant contrast delivered to the eye by the imaging system

C_T = threshold contrast from Equation (5) or (6)

<u>Calculation of Single Glimpse Probability of Detection</u>

The equation for the single glimpse probability of detection may now be expressed as:

$$P_d = P_A * 1/\sqrt{G} * P_{HS} \tag{10}$$

where

P_A = probability that the target is in the pilots instantaneous field of view

G = degradation factor due to clutter

P_{HS} = probability that the pilot can make a positive determination of a target given one is located on the monitor screen.

Cumulative Probability of Detection

Having established the probability of detection for a single glimpse by Equation (9), the cumulative probability of detection is expressed by[33]:

$$P_D(N) = 1 - \prod_{i=1}^{N} (1 - P_d) \tag{11}$$

where

N	=	total number of glimpses
P_d	=	probability of detection for a single glimpse

The product term is used in the calculation because the probability of detection, P_d, is different and independent for each glimpse i = 1 to N.

The cumulative probability of detection can be determined for a time interval T by multiplying the total number of glimpses N, by the time per glimpse (in our case 1/2 second).

Cumulative Probability of Acquisition

The cumulative probability of target acquisition includes the time required for the pilot to recognize and identify a target. Once a target is identified, the pilot must recognize it as a particular class of objects, such as a RED helicopter. The pilot must then identify the target as a specific sub class, such as a HIND-D, to complete his engagement decision. At this time the pilot cam be assured that the target he is about to engage is not a friendly aircraft.

The cumulative probability of acquisition may be defined as[33]:

$$P_{AQ}(T) = P_D(T - \Delta T) \tag{12}$$

where ΔT is the time required by the pilot to recognize and identify the target and

prepare his armament for launch.

Probability of Launch

Once the target has been identified and acquired, the pilot must launch the missile as quickly as possible in order to enhance destruction of the target while increasing his own change of survival. Therefore, each missile launch must be preceded by a time delay of some duration.

Several different approaches have been taken to model the time required for a human operator to perform a specified task. The time required for a pilot to launch a missile will vary from engagement to engagement, depending upon the situational circumstances present at that time.

One approach to quantifying the time delay is to establish, or estimate if necessary, the lower and upper limits on the time delay and assume that the distribution is uniform. This assumption results in the equal probability of occurrence of any time delay between the minimum and maximum limits, and offers a sound approximation when the actual distribution of time delay is undetermined. The GEM utilizes the uniform distribution to estimate this time delay and is used as a basis for the methodology which follows.

The probability of launch is derived from the cumulative probability of acquisition, because it is this function which directly precedes the launch of a missile. To estimate this probability function, let

Δt = 5 sec = length of sample time intervals used for computation of the function

t_{MIN} = 2t = minimum time to acquire a target in sample time intervals (= 10 secs)

$t_{MAX} \quad = \quad 5t \quad = \quad$ maximum time to acquire a target in sample time intervals (= 25 secs)

The values for t_{MIN} and t_{MAX} are similar to those time line estimates used in CARMONETTE[9].

To calculate the probability of launch at time t, the probability of acquisition function must be evaluated and averaged over the time spread from t_{MIN} to t_{MAX}. Thus, $P_{LNCH}(t)$, the probability of launch at the current time may be determined from:

$$P_{LNCH}(t) = \frac{P_{AQ}(t - 2\Delta t) + P_{AQ}(t - 3\Delta t) + P_{AQ}(t - 4\Delta t) + P_{AQ}(t - 5\Delta t)}{4} \tag{13}$$

A block diagram depicting the computation of the probability of launch is illustrated in Figure 11.

Probability of Missile Intercept

The probability of missile intercept, P_{MI}, is derived from the probability of launch function. The intercept function is a time delayed function in which the time delay corresponds to the time of flight required for the missile to reach the target. Figure 12 offers an illustration of the time delay relationship between the probabilities of acquisition, launch and intercept.

Assuming the missile flies a straight path and constant velocity to the target, the time of flight (TOF) may be calculated from[25]:

$$TOF = \frac{RNG_{TGT} - RNG_{MML}}{VEL_{MSL}} + t_{MMR} \tag{14}$$

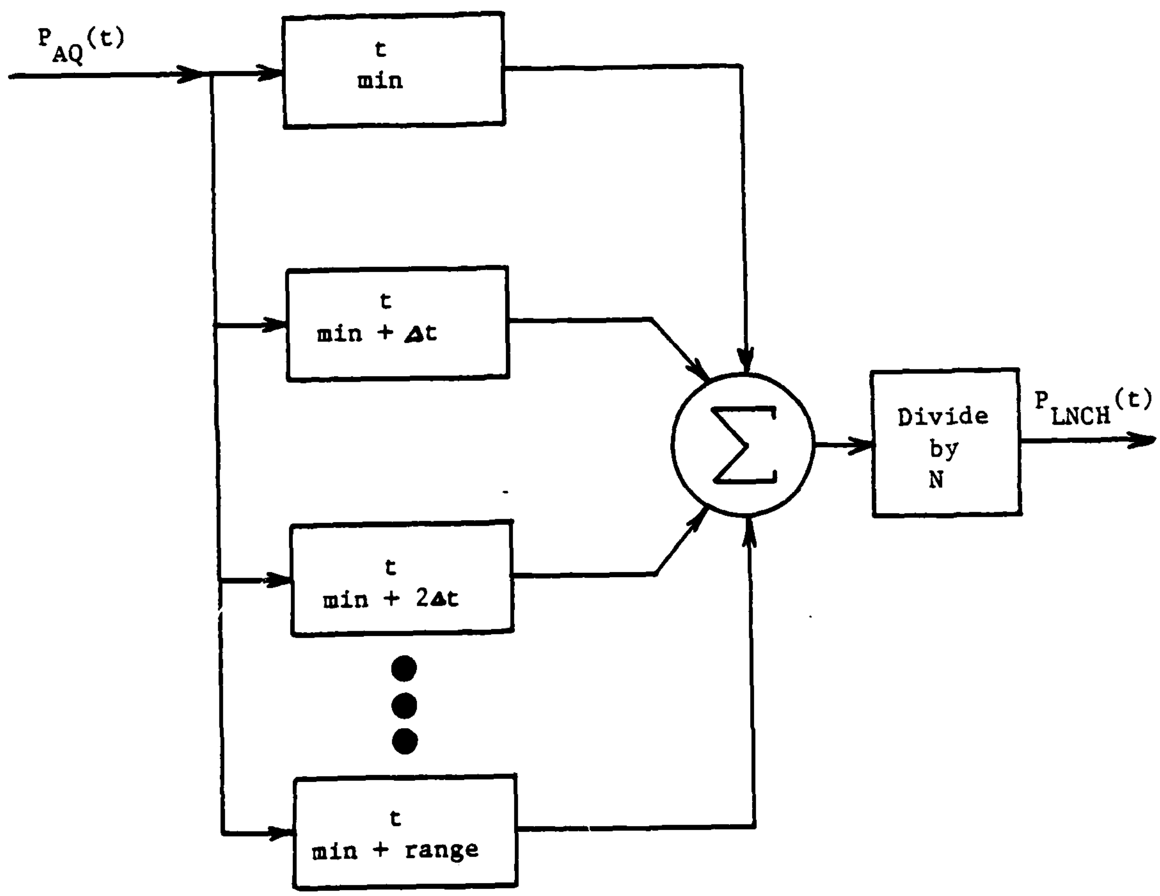

Figure 11. Probability of Launch Block Diagram

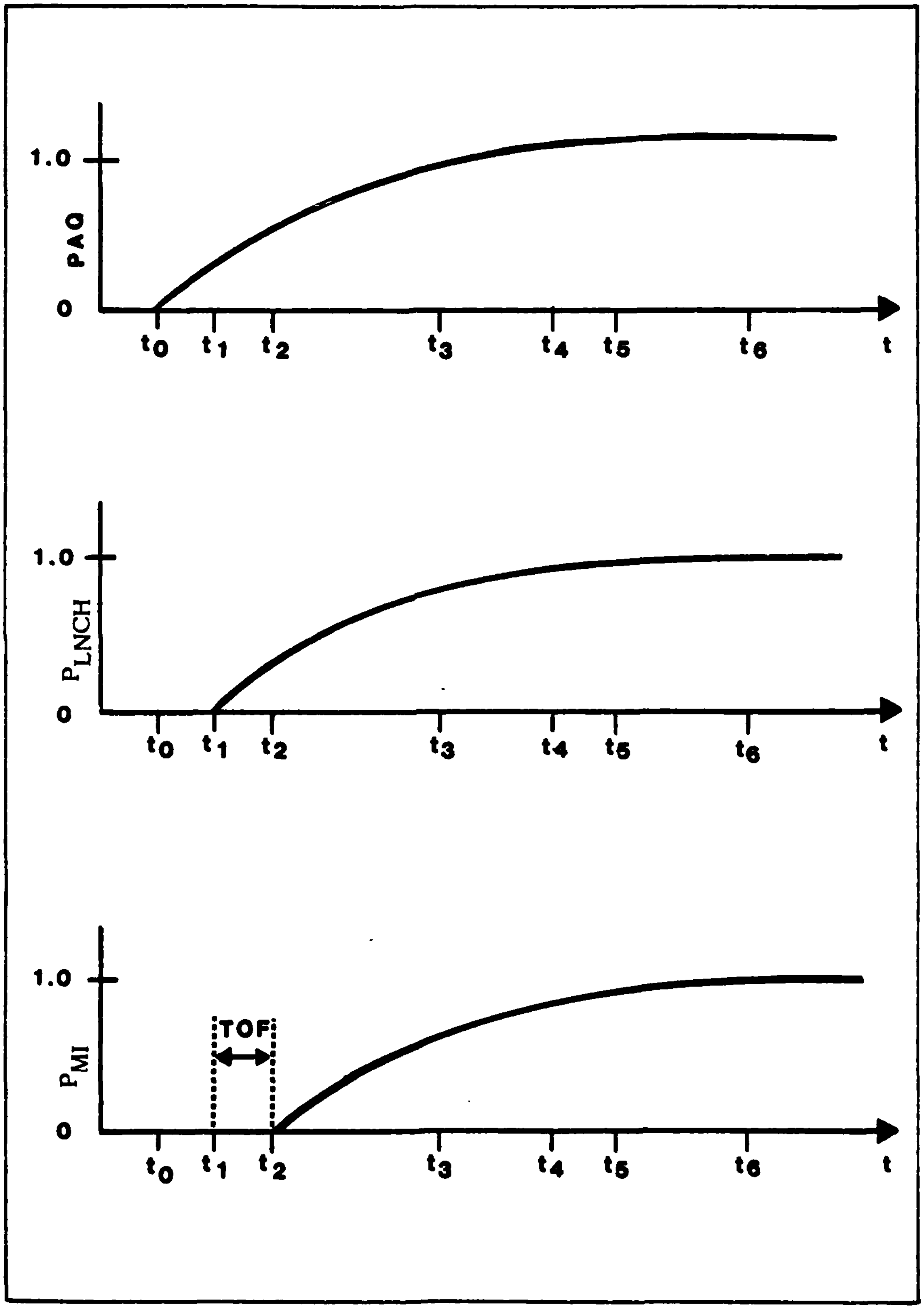

Figure 12. Missile Launch/Intercept Time Delays

where

RNG_{TGT} = target range

RNG_{MML} = minimum missile launch range

VEL_{MSL} = missile velocity

t_{MMR} = time to minimum missile range

GEM incorporates a backwards approach to calculate the probability of missile intercept. Rather than compute the missile intercept range for a given missile trajectory, GEM computes when a missile would have been launched to impact with the target aircraft at the current time. This method of calculation is more efficient for computer simulation since it precludes the requirement to simulate a missile launch for every time interval in which the probability of launch is greater than zero. The two methods have been shown to provide consistent results.

The equation for the probability of missile intercept becomes[25]:

$$P_{MI}(t) = P_{LNCH}(t - ITOF * \Delta t) \qquad (15)$$

where

P_{LNCH} = probability of launch function

t = current time

$ITOF$ = missile TOF ÷ sampling time increment (Δt), rounded to the nearest integer

Probability of Kill

Having determined the probability of missile intercept, the probability of kill given that the missile intercepted the target, P_{KGI}, must be evaluated.

The P_{KGI} function is dependent upon the vulnerability characteristics of a particular airframe against a specific weapon system. A detailed methodology for the determination of these functions is discussed by Ball[4]. The most critical factor in the calculation is the missile missed distance.

The determination of the missed distance is best calculated by a six degree of freedom missile flyout model. These models are commonly developed in the design, research and development of a given missile weapon system. Such a model can accurately incorporate tracking error, aerodynamic and explosive characteristics of the missile as well as track the missile flight path while enroute to the target. The model computes the probability of kill based upon the distance of missile detonation from the target and the resultant blast and fragmentation effects. Figures 13 and 14 depict the effects of blast and fragmentation on target probability of kill.

Utilizing the flyout model, a missed distance is calculated for each time increment in which P_{LNCH} is greater than zero. This procedure is illustrated in Figure 15. With the missed distance for a given missile system determined, the P_{KGI} may be calculated from[25]:

$$P_{KGI} = \frac{1}{1 + \left(\frac{MISS(t)}{CEP}\right)^n} \tag{16}$$

where

$MISS(t)$ = missile missed distance at time t

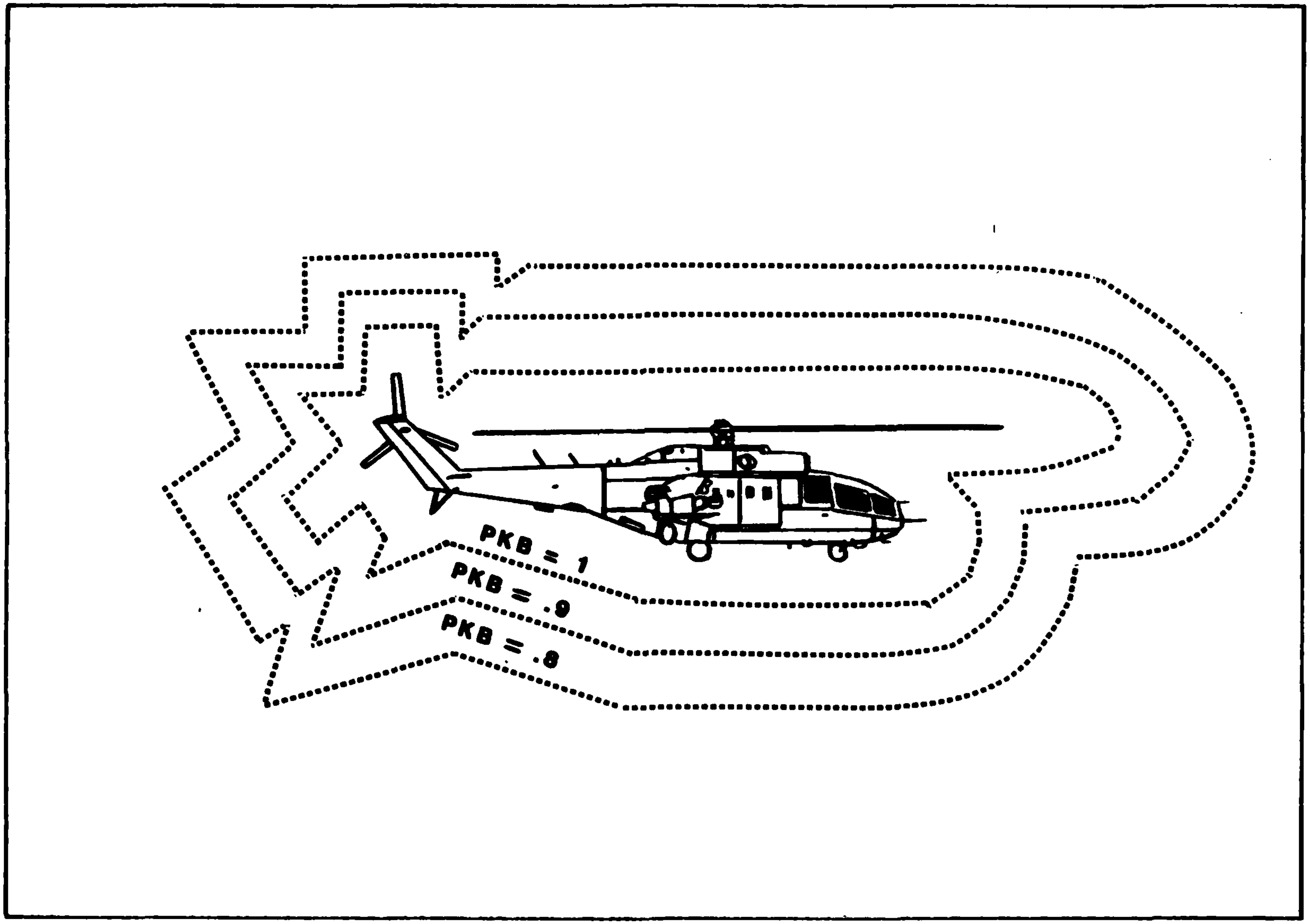

Figure 13. Missile Blast Effects

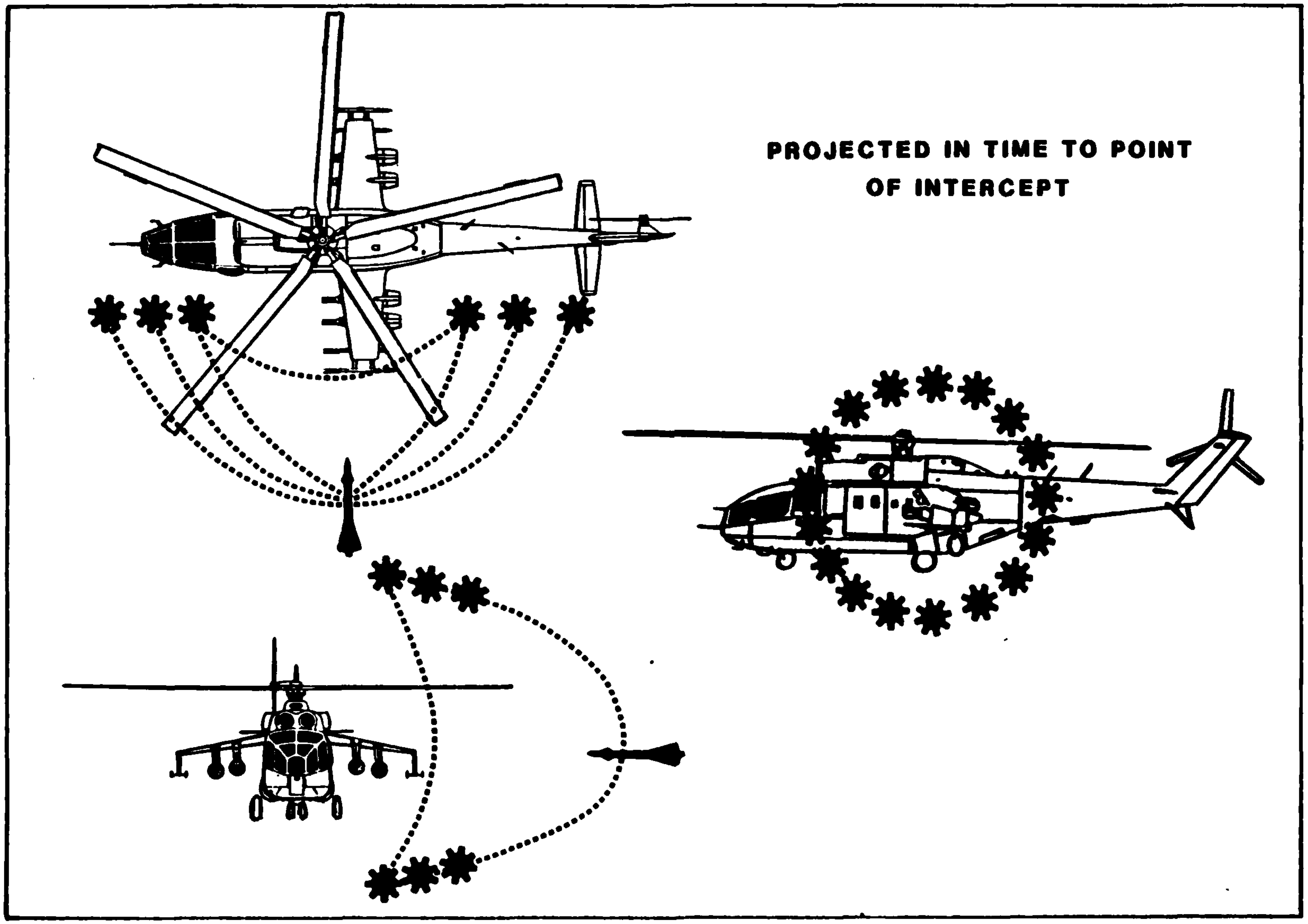

Figure 14. Missile Fragmentation Effects

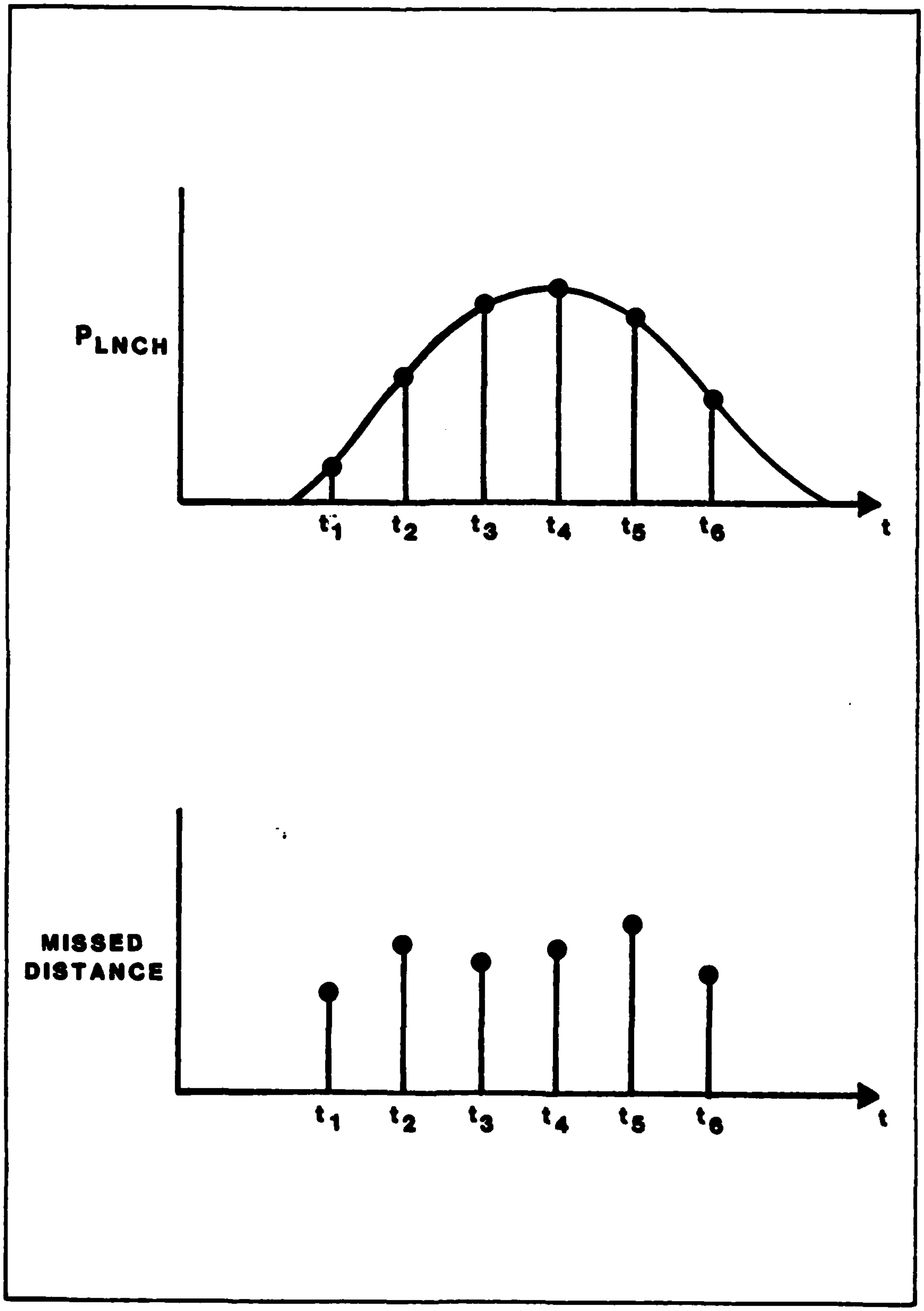

Figure 15. Determination of Missed Distance Given Launch

CEP = missile missed distance for specific system resulting in 50% P_K

n = exponent to fit curve describing aircraft vulnerability to specific missile system

With the P_{KGI} derived from Equation (15), the total probability of kill may be calculated by:

$$P_K(t) = P_K(t - \Delta t) + P_{KGI}(t) * P_{MI}(t - \Delta t) \qquad (17)$$

In many models and simulations, the resultant P_K calculation is compared to a threshold to determine if a kill has taken place. If the calculated P_K is greater than this threshold, a kill is registered and a player is removed from the simulation. In other cases, a random number may be drawn to determine if a kill has been registered.

Both of these methods may be improved upon by determining the actual shape of the P_K distribution. By maintaining the missile-target aspect angle constant and allowing the aircraft-target range to vary, the P_K distribution for range may be determined. Figure 16 depicts such a representation.

This method of depiction offer significant advantages over the common kill/no kill results. The analyst can see how the P_K function varies with range to include that range for which the P_K is a maximum. A more detailed application of this P_K distribution will be demonstrated in Chapter V.

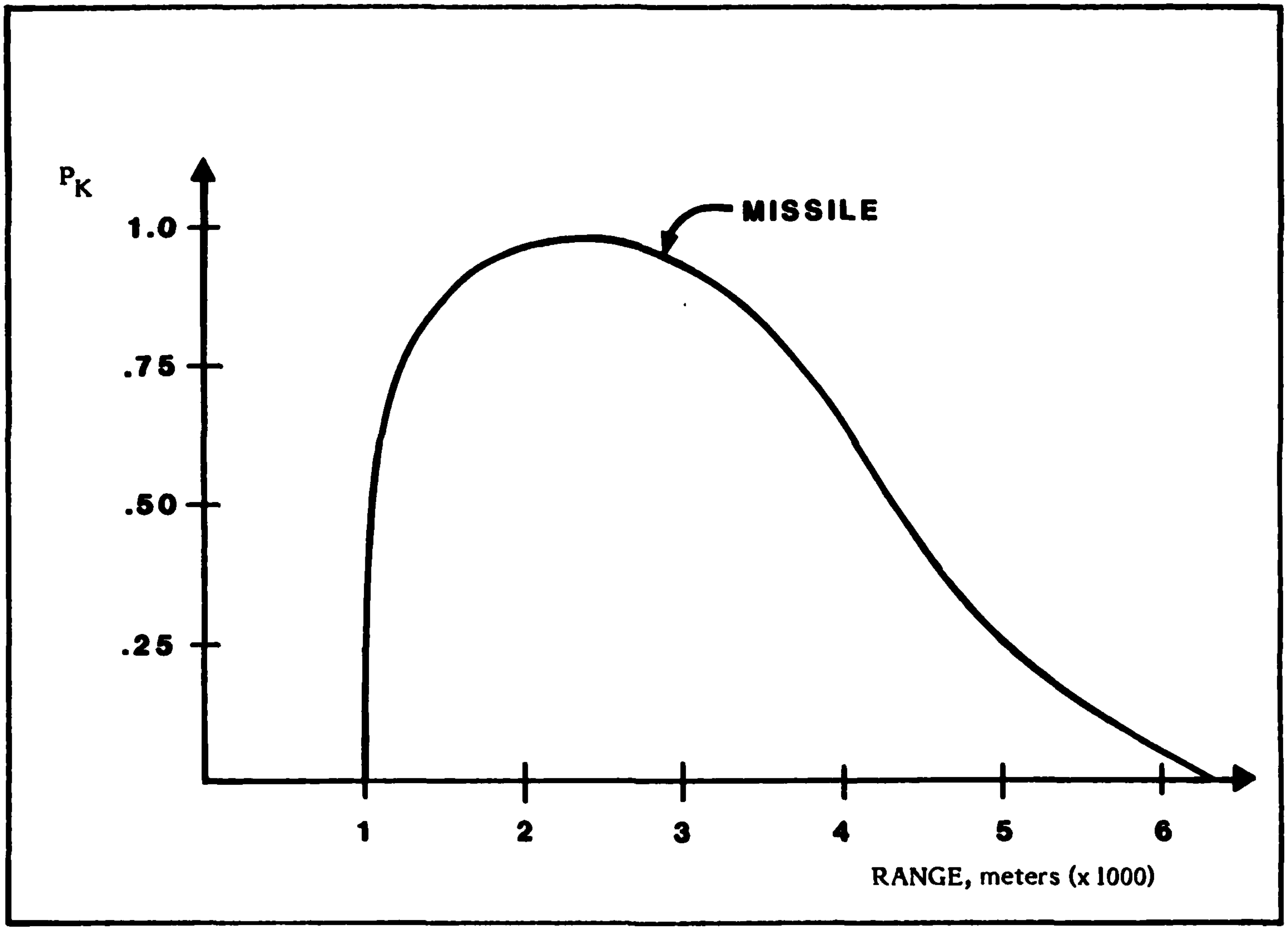

Figure 16. Probability of Kill Versus Range for a Given Aspect Angle

CHAPTER IV

EVALUATION AND VALIDATION

Evaluation

The topic of model evaluation is highly subjective, depending primarily upon which perspective is assumed -- developer or user. These differing points of view often lead to separate objectives and goals, making a difficult task even more so.

Simply stated, the goodness of a model is judged by how well it achieves its purpose[17]. The criterion required to assess this achievement may be difficult to establish and agree upon. Hence the subjective and controversial nature of model evaluation.

However, the degree to which a model achieves its purpose should not be the only standard by which a model is critiqued. In addition to achieving its purpose, the model must be credible in that it accurately portrays the process or phenomenon it was designed to represent. The range of applicability must be adequate to include those cases or scenarios for which it was designed. The model must be cost effective, in terms of both time and money expended. Finally, the model must be understandable by the primary user. All other considerations are contingent upon this one. The user who does not understand or cannot confidently manipulate the model to achieve his desired objective will probably not consider it satisfactory by any other standard.

To assist the user in selection of a model which would best suit his needs, compilations such as the Catalogue of War Games and Combat Simulations[9] and the Inventory of TRADOC Models[18] list detailed descriptions of model capabilities.

These descriptions aid the user in the evaluation of candidate models which conform to his purpose and objective.

The evaluation of an air-to-air engagement methodology is made more difficult than normally experienced for two distinct reasons: (1) it is a military combat model, and (2) it is "futuristic" in nature.

Military models have traditionally been difficult to evaluate due to the complexity and ambiguity of the system they are designed to represent. Hausrath[13] identifies many combat related considerations which limit a models' accurate representation. It is most difficult to definitively gauge a pilots reaction within the confines of an armed conflict. One's reaction to a situation in a training environment or simulation may prove to be quite different than that in an actual conflict.

In addition, the evaluation of this model is more difficult because the U.S. Army has yet to engage in an air-to-air engagement utilizing the equipment and capabilities defined here. There is no precedent with which to compare. The model is "futuristic" in the sense that current techniques and methodologies are combined to formulate a model which predicts the resultant vulnerability in an air-to-air engagement. Field testing is required to ultimately assess the accuracy and validity of the model.

Validation

As a fundamental part of the evaluation process, validating a model is both critical and essential. Banks and Carson[5] refer to validation as

> . . . the act of determining that a model is an accurate representation of the real system. Validation is usually achieved through the calibration of the model, an iterative process of comparing the model to actual system behavior and using the discrepancies between the two, and insights gained, to improve the model. This process is repeated until model accuracy is judged to be acceptable.

The objective of this validation process is to[5]:

> (1) produce a model that represents true system behavior closely enough for the model to be used as a substitute for the actual system for the purpose of experimenting with the system and (2) increase to an acceptable level the credibility of the model, so that the model will be used by managers and other decision makers.

This validation process may not be as easily executed as it seems. Payne[28] argues that all models, because they are abstractions, may be considered invalid. Regardless of the expenditures in time and money, many properties of the actual system will not be incorporated in the model. Undoubtedly an approximation will be included, such as a true non-linear relationship represented by a linear process. These abstractions are indicative of pitfalls which must be overcome if a model is to be declared a "valid" representation of the real system.

Hoeber[15] recommends that the validation process be attacked at three levels-- "in-perspective, in-principle and in-practice." The perspective level evaluates the model with respect to applicability, detail and other models with similar objectives. Next the underlying principles are appraised for adequacy and realism. Finally, the practice level compares the model's results and predictive ability with actual observed data.

The complete validation of the model presented in this research will be restricted by a lack of observed data required by Hoeber's "in-practice" level. The U. S. Army has no combat data and very little test data on air-to-air engagements as modeled here. Consequently, increased emphasis must be placed upon the perspective and principles which form the basis for the model.

Since little observed data is available, the validity of this model will depend primarily upon its face value. Law and Kelton[21] present guidelines which assist in the accomplishment of this critical step of the validation process. To

insure the model has been properly developed, the analyst should incorporate all available information to include conversation with experts, existing theory, observation of the system, general knowledge and intuition. In all but one category, the development of this model has conformed to the guidelines of Law and Kelton which aid in development of a model with high face validity.

The primary strength of this methodology lies in its' basis upon existing theory. The physical aspects of the EO system are based upon accepted laws of science and engineering. These representations and concepts were supported through dialogue with other analysts, engineers and aviators, each very knowledgeable in his respective field of expertise. Numerous calculations required within the methodology were extracted from simulation models which have been validated and in current use. These validated concepts form the incremental blocks with which the entire model was constructed. Finally, as is the case with any model building, the intuition of the modeler is depended upon to put the pieces together as he hypothesizes they operate. This aspect may very well be more art than science or procedure.

The only factor absent from those which Law and Kelton recommend to establish a high face validity is observations of the system. The Army will not begin to conduct formal testing of air-to-air helicopter engagements until September 1985. After this testing, observed data will be available which can be used for comparison with the model output.

This lack of observed data describes the "conceptual validation" process discussed by Banks and Carson[5]. Without actual data for comparison, the model represents a concept as to how the actual system should perform. The validation process then becomes an iterative process in which the model is revised as more

and more test and observed data becomes available. Such an iterative validation process is illustrated in Figure 17. The validation process is never actually complete, but continues to evolve as more insight and knowledge is obtained about the actual system under study.

Recalibration

In the past, a system may have been modeled after it was fielded and used primarily as a device for conducting sensitivity analysis. However, an accurate methodology can be of great assistance prior to conducting system tests. Analysis of the methodology will identify assumptions and concepts which should be addressed during the testing to prove or disprove their validity.

Mathiasmeier[23] dilineates a procedure for deriving a hypothesis based upon the established model then testing the hypothesis as a result of observed system data. This procedure complements the reiterative model validation process presented by Banks and Carson[5].

As an illustration of this recalibration process, a procedure for the testing of an assumption in the developed methodology will be presented. The U. S. Army Combat Development Experiment Command (CDEC) will initiate air-to-air engagement testing at Fort Hunter - Liggett, California in September 1985. This will constitute the first opportunity to collect observed data on the actual system modeled here.

An assumption in the developed methodology is that the time delay for a pilot to acquire a target is uniformly distril ted between some minimum and maximum value. This is a procedure applied in many instances in which observed data is not available.

However, other factors may be entered into consideration which would

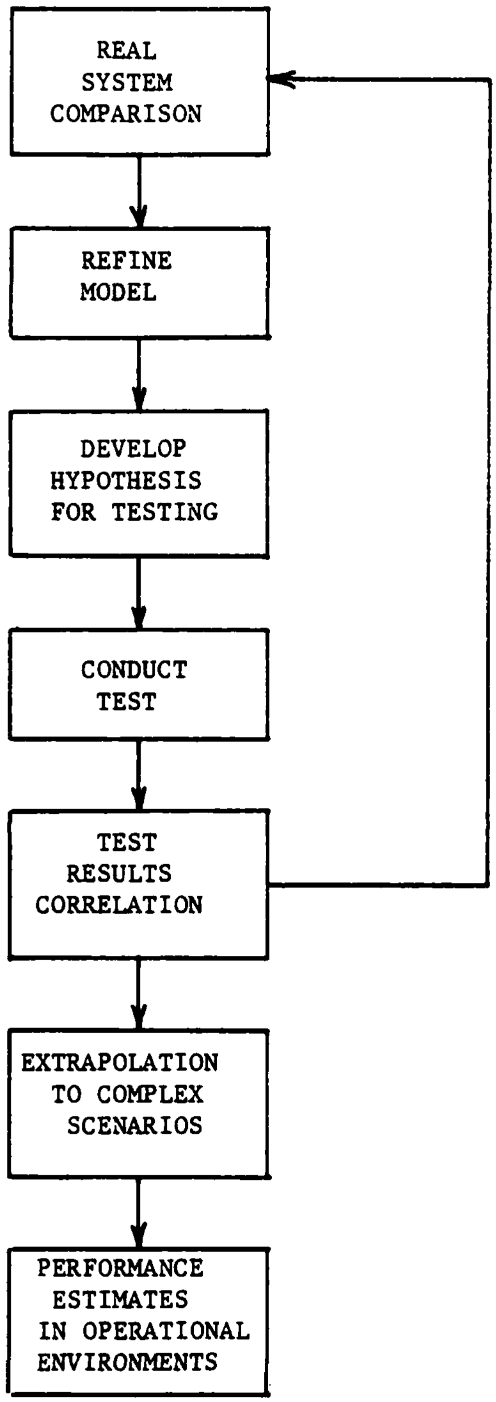

Figure 17. Iterative Validation Process

allow us to recalibrate the model based upon observed data and knowledge of similar operational settings. Pilots undergo extensive training to improve their skills at tracking and firing on a target aircraft. The training is repetitive and designed to increase his proficiency at performing those manual and mental tasks required to get a missile down range. The resultant effect of this training, as evidenced by the study of other operator tasks, is to reduce the range of time delays while establishing an average time required by the average pilot under the same circumstances. The predominance of delay times will lie somewhere near the mean with fewer cases located near the minimum and maximum times.

Another factor which influences the length of time delay experienced by the pilot is his workload during the acquisition process. The workload is the number of other tasks the pilot must perform as he acquires his target and is a function of many factors to include aircraft orientation and range with respect to the target, weapons status, and battlefield obscurations. As the pilot workload increases, the length of the time delay should increase and the mean value should increase as well.

A modification of the exisitng methodology to include the two factors described above would allow the time delay to be represented by a triangular (a, b, c) rather than normal distribution. This would reduce the spread of delay times and allow modification of the (a, b, c) parameters by a workload coefficient, W.

The workload coefficient is a factor greater than or equal to one which could be selected by the user to define his desired scenario. Table 6 depicts the range of sample pilot workload coefficients for user input.

Table 6. Pilot Workload Coefficients (W)

W	Level of Workload
1.0	Normal Workload
1.3	Light Workload
1.6	Moderate Workload
2.0	Heavy Workload

As an example, let the distribution of time delays be described by a triangular (a, b, c) distribution where $a < c < b$ and

$$\text{range} = a, b$$

$$\text{mode (c)} = \frac{b-a}{2}$$

$$\text{mean} = \frac{a + b + c}{3}$$

The value of the mode c, the most likely time to complete the target acquisition, is subjectively determined to be half the range a, b . Using the same values for the range of time delays illustrated in Chapter III, let a = 5 sec. and b = 25 sec. Let $W = 1.3$, indicating the pilot experiences a light workload during the target acquisition process.

The new maximum value for the time delay, b', is calculated by multiplying the previous limit by the workload coefficient, W. The minimum time delay remains constant. This yields

$$b' = b * W = 25 * 1.3 = 32.5 \text{ sec.}$$

$$a' = a = 5 \text{ sec.}$$

$$c' = \frac{b' - a'}{2} = 13.75 \text{ sec.}$$

$$\text{mean} = \frac{a' + b' + c'}{3} = 17.08 \text{ sec.}$$

The affect of this modification has been to extend both the range and mean of the time delay required to acquire a target due to the workload experienced by the pilot. It is an example of the recalibration and reiterative validation process expressed by Mathiasmeier and Banks and Carson.

Perhaps a more accurate description of the processes commonly referred to as verification and validation may be offered by Hughes[17]. Hughes redefines the process as corroboration, in which the developer merely attempts "to make a better case than before." Certainly many of the ambiguities and subjective standards commonly associated with the verification and validation processes would be reduced by an effort to corroborate the model.

CHAPTER V

RESULTS AND RECOMMENDATIONS

Recommended Application to Aviation Tactics

The developed methodology and representation of probability of kill as a function of range for a given aspect angle can be utilized to enhance the analysis of other aspects of the air-to-air engagement. In this respect, the application assists in fulfilling what DeLong[7] describes as a need for new methods

> . . . that sort out mission and equipment possibilities and evaluate likely engagement conditions, that explore tactics as well as equipment, that can be verified by actual or simulated air combat, and that are sensitive to the capabilities of detection and acquisition sensors and potential mixes of weapons.

Figure 16 depicts the variation in probability of kill as a function of range. For a given probability of kill threshold, the minimum and maximum ranges for engagement can be interpolated from the graph. Execution of the methodology for various cardinal aspect angles provides the analyst with a minimum and maximum engagement range to achieve the desired probability of kill. This information can be applied to research and development efforts like those described in [38], in which helicopter maneuverability and agility requirements were being evaluated for "short and long range" engagements. No definitions were provided for what constituted short and long ranges. Selection of a desired probability of kill threshold would allow the analystto accurately evaluate maneuverability and agility requirements at the resultant minimum and maximum ranges. In this case, "short and long range" engagements would be selected for the tested weapon-target combination and desired probability of kill threshold.

An additional application of the prescribed methodology can be made to the

development of aviation air-to-air combat tactics. The Directorate of Combined Arms Tactics (DCAT), Fort Rucker, Alabama is currently developing the tactics and doctrine which will allow an Army aviator to fight and survive an air-to-air battle. The development of these tactics is in the early stages due primarily to the lack of a historical precedent or observable test data. Aviation tactics will also be evaluated in the testing scheduled to commence in September 1985.

Two pieces of information critical to the pilots' success in an air-to-air engagement are the optimum aspect angle of attack and the engagement ranges which will insure an adequate probability of kill. This information is readily obtainable by execution of the developed methodology and incorporation of the data into a decision logic for the pilot.

For illustration purposes, this scenario will match a friendly helicopter armed with an air-to-air Stinger (ATAS) missile against a HIND aggressor aircraft.

Initially, numerous cardinal aspect angles are selected as input to the methdology. Figure 18 suggests aspect angles for analysis against the HIND. The methodology is executed for each on-board weapon system and selected aspect angles for ranges varying from zero to the maximum range of the weapon. The result is a distribution which provides the changes in probability of kill over range for the selected aspect angle. Graphical representation of the probability of kill curves for all weapon systems, such as Figure 19, provides a means for selecting the optimum weapon as a function of range.

Selection of a threshold probability of kill results in an optimum aspect angle and engagement range the pilot should strive to attain in his air-to-air engagement. Selection of the probability of kill threshold is no easy task. Essentially, the pilot must ask himself, "what probability of kill must I be assured

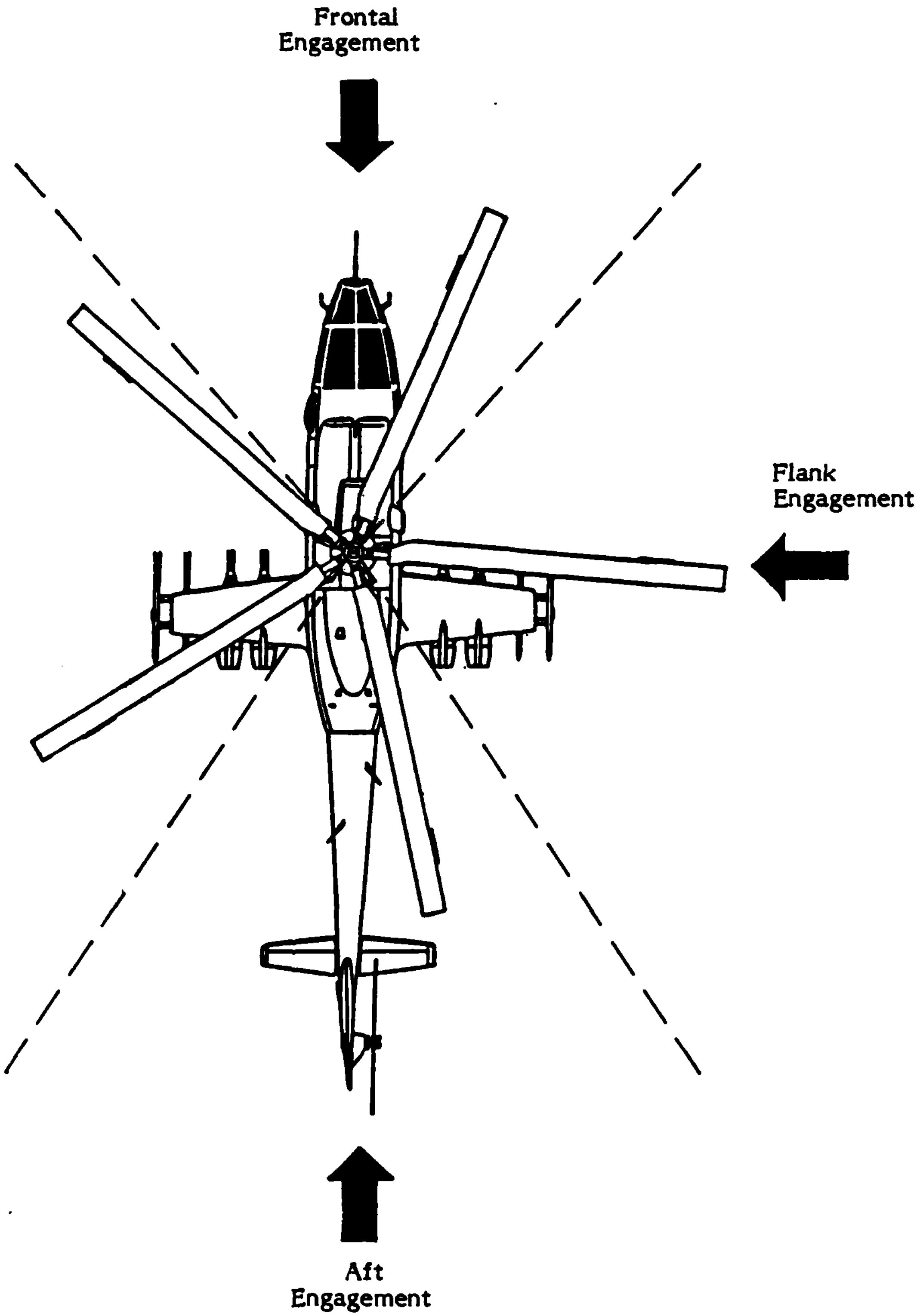

Figure 18. Aspect Angle Designations

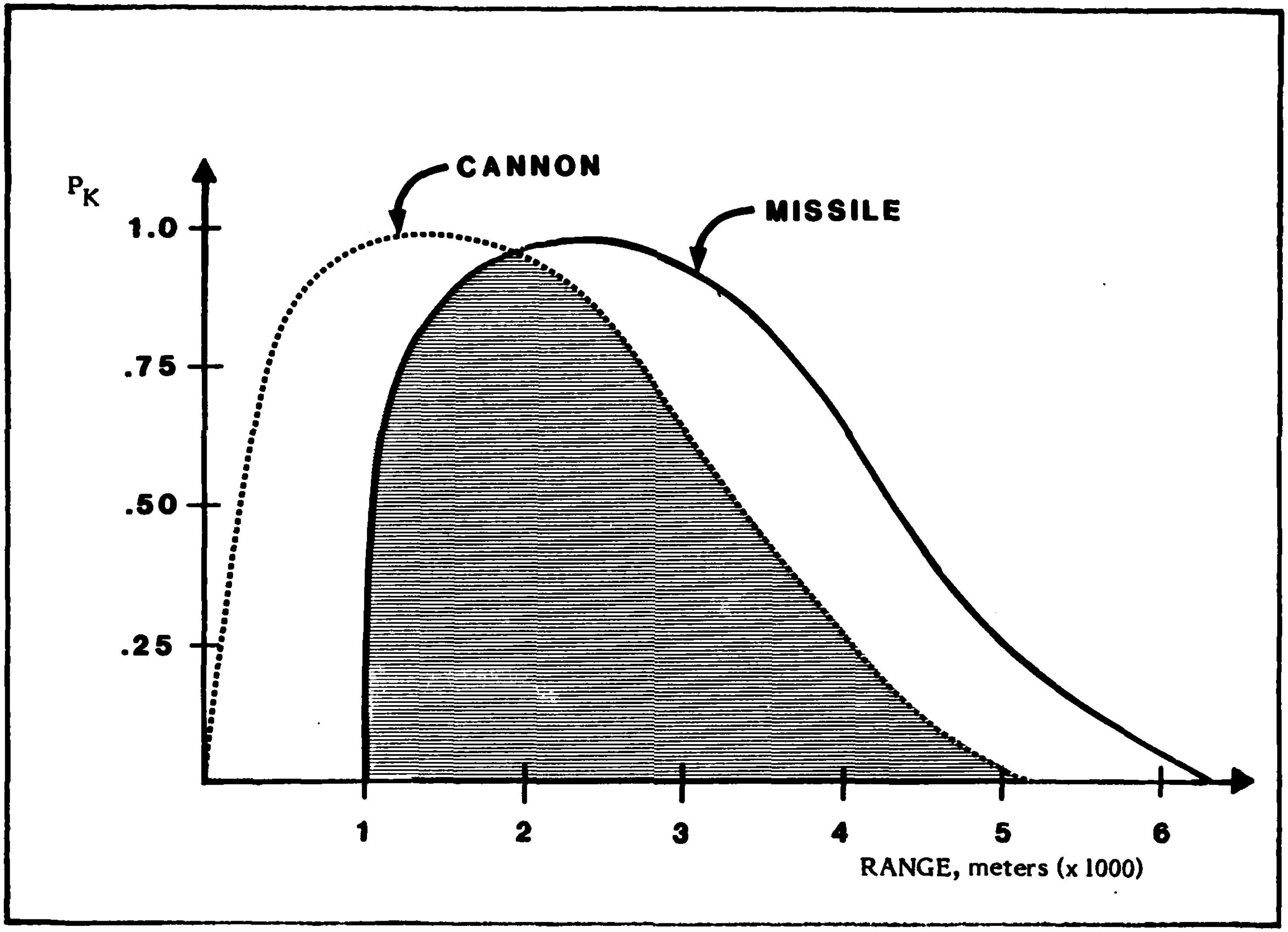

Figure 19. Multiple Weapon System Probability of Kill Versus Range for a Given Aspect Angle

before I will voluntarily engage myself in an air-to-air conflict?"

If the friendly aircraft is attacked, there is no decision to make. The pilot must maneuver and return fire as necessary to survive the engagement. However, if the friendly aircraft is the aggressor he has the option of avoiding the target and continuing the mission or engaging it. If the choice is to engage, the pilot must know what aspect angle and range to achieve in order to insure an adequate probability of kill.

The objective here is not to overburden the pilot with a multitude of aspect angle and engagement range combinations. The output of the analysis should be conducted to identify only those angle/range combinations which maximize the probability of kill. The optimum position for firing and maneuvering required to achieve it must be second nature -- the battle is far too intense for it to be otherwise.

Figure 20 depicts a decision logic which can be formulated as the result of the application of this methodology to tactics. The portion of the decision logic inside the dotted lines represents those thought processes which may be enhanced through the execution of the methodology and application of the results to aviation training. As with any other application, the logic should be validated through simulated air-to-air engagements during field tests. The combined application of these methods will allow the development of rules of engagement to assist the pilot in an actual air-to-air encounter.

Conclusions

The development of the proposed air-to-air engagement methodology is based upon a survey of numerous models and simulations currently in use. Many of the models do not represent all the functions necessary to define the entire system,

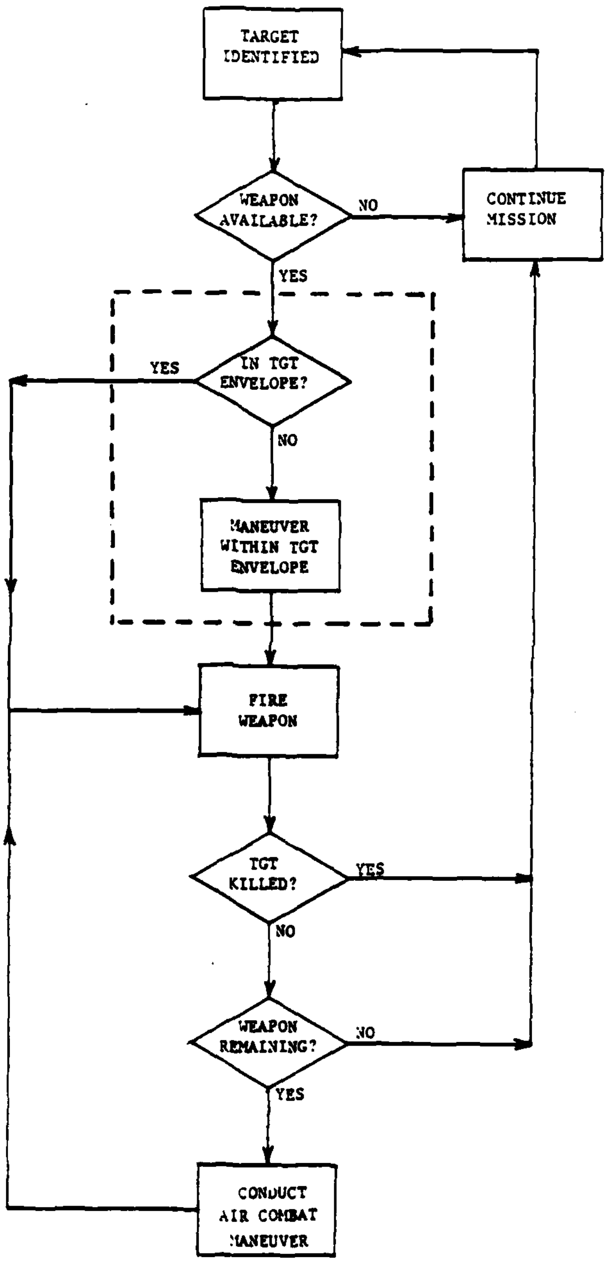

Figure 20. Air-to-Air Engagement Decision Logic

but offer detailed representations of their designed purpose. Such is the case with HELMS, which calculates excellent flight path data, but doesn't provide for actual air-to-air play. Many of the concepts and algorithms utilized in these models were adopted as a basis for the demonstrated methodology.

The Optical-Zinger (OZ) model was used as a standard for many of the EO detection functions. This model provides an excellent description of the EO processes and has often been used as a standard by which other models have been evaluated. The GEM, developed by the Georgia Tech Research Institute, provided the basis for the missile launch, intercept and kill functions.

The survey of existing models and simulations provided the framework for the development of a methodology which calculates the vulnerability (probability of kill) for a rotary wing air-to-air combat engagement. Algorithms are presented which expose the internal structure of the primal processes required in such an engagement. The methodology is then extended to illustrate how the probability of kill may be depicted as a function of range for a given aspect angle. This method of presentation constitutes a significant improvement over the more common kill/no kill output results.

Criterion for evaluating the validity of the methodology are identified and analyzed. Recalibration of the model based upon future test data is demonstrated. The recalibration process offers a means for reiterative model improvement and the identification of areas warranting further testing.

Finally, the results of the methodology are applied to the training of U.S. Army rotary wing pilots. The result is a decision logic which will enhance the survivability of Army aircrews in an air-to-air engagement.

APPENDIX A

Acronym List

AEM	Automated Encounter Model
ATA	air-to-air
ATAS	air-to-air Stinger missile
BLUE	friendly helicopter
CDEC	Combat Development Experimental Command
DCAT	Directorate of Combined Arms Tactics, Fort Rucker, Alabama
DCD	Directorate of Combat Developments, Fort Rucker, Alabama
DVO	day view optics
EO	electro-optical
FLIR	forward looking infrared
FOV	field of view
GAO	Government Accounting Office
GEM	General Effectiveness Model
GTRI	Georgia Tech Research Institute
HACES	Helicopter Air Combat Effectiveness Simulation
HELMS	Helicopter Mission Survivability Model
HIND-D	Soviet Attack Helicopter
HSAM	Helicopter Survivability Assessment Model
IR	Infrared
LHX	Light Helicopter, Experimental
NOE	nap-of-the-earth
OZ	Optical Zinger Model
RED	enemy (aggressor) helicopter

SAM	surface-to-air missile
SPAM	Self Protection Analysis Model
TADS	Target Acquisition Designation Sight
TOA	trade-off analysis
TOF	time of flight
TV	television
WES	Waterways Experimental Station, Vicksburg, Mississippi

APPENDIX B

Variable List

$\lvert C \rvert$	net resultant contrast delivered to eye by imaging system
CEP	circular error probable
C_T	image contrast threshold
D	distance from pilot eye to display monitor screen
G	scene complexity factor for clutter
H, W	actual height and width of TV monitor screen
ITOF	missile time of flight divided by a sampling time increment, rounded to nearest integer
L	representative aircraft dimension
MISS(t)	missed distance at time = t
n	exponent to fit curve describing aircraft vulnerability to specific weapon system
P_A	probability of target in the instantaneous field of view
P_{AQ}	cumulative probability of acquisition
P_D	cumulative probability of detection
P_d	probability of detection for a single glimpse
P_{HS}	probability that, given a target is displayed on the optical device, clarity and contrast will be sufficient to permit positive determination by the pi' ɩt
P_K	probability of kill
P_{KB}	probability of kill due to blast effects
P_{KGI}	probability of kill given intercept

P_{LNCH}	probability of launch
P_{MI}	probability of missile intercept
P_S	probability of survival
R_S	aircraft-target slant range
RNG_{MML}	minimum missile launch range
RNG_{TGT}	target range
$r(t)$	failure (or hazard) function
t_{MAX}	maximum time
t_{MIN}	minimum time
t_{MMR}	time to minimum missile range
VEL_{MSL}	missile velocity
W	pilot work load coefficient
λ	exponential rate
α	eye-apparent angular size of aircraft image
θ	angular location of image with respect to foveal axis
θ_I	instantaneous angular field of view
θ_T	total angular sky sector to be searched
θ_v, θ_h	vertical and horizontal extent of TV system
$\frac{10800}{\pi}$	conversion from radians to arc minutes

APPENDIX C

A. SCENARIO DEFINITION

1. Geographic Area
2. Micro-Terrain
3. BLUE and RED Missions
4. Threat ADA
5. Threat Helicopters
6. BLUE Helicopters
7. Visibility
8. Targets

B. HELICOPTER CHARACTERISTICS

1. Model Dynamics and Performance Limits
    a. Model Gains and Time Constants
    b. Roll Parameters
    c. Performance Limits
    d. NOE Computation Parameters
2. Helicopter Observables
    a. Visual Area
    b. Exposed Area
    c. IR Signature
    d. Radar Cross Section
    e. Visual Contrast and Brightness Factors
    f. Acoustic Signature

3. Helicopter Sensors and Visual Detection Parameters

   a. VFT in Forward Flight

   b. VFT in Hover

   c. Glimpse Rate

   d. Visual Scan Sector

   e. EO (TV) and IR(FLIR) Sensors

   f. Radar Warning Receivers (RWR)

4. Helicopter Weapons and Fire Control System

   a. Helicopter Gun Parameters

   b. Helicopter Missile Parameters

   c. Weapon Availability

   d. Weapon Prioritization

   e. Fire Control System Time Delay

   f. Turn into Target

   g. Time Delay for Indirect Fire

5. Helicopter Tactics and Maneuvers

   a. Evasion Logic

   b. Attack Enable Logic

   c. Fire-on-the-Move/Stop

   d. Statistical Height Variations

   e. Come-out-of-Hover Logic

   f. Threat Helicopter Attack

   g. Modify Probability of Detection

C. AIR DEFENSE SYSTEM

1. Command and Control Center

2. Surface-to-Air Missiles

3. Anti-Aircraft Artillery
4. Air Defense Radars
5. ECM Effects
6. Detectability Parameters

D. TARGETS

1. Detectability Parameters
2. Multiple Targets
3. Target Speed

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